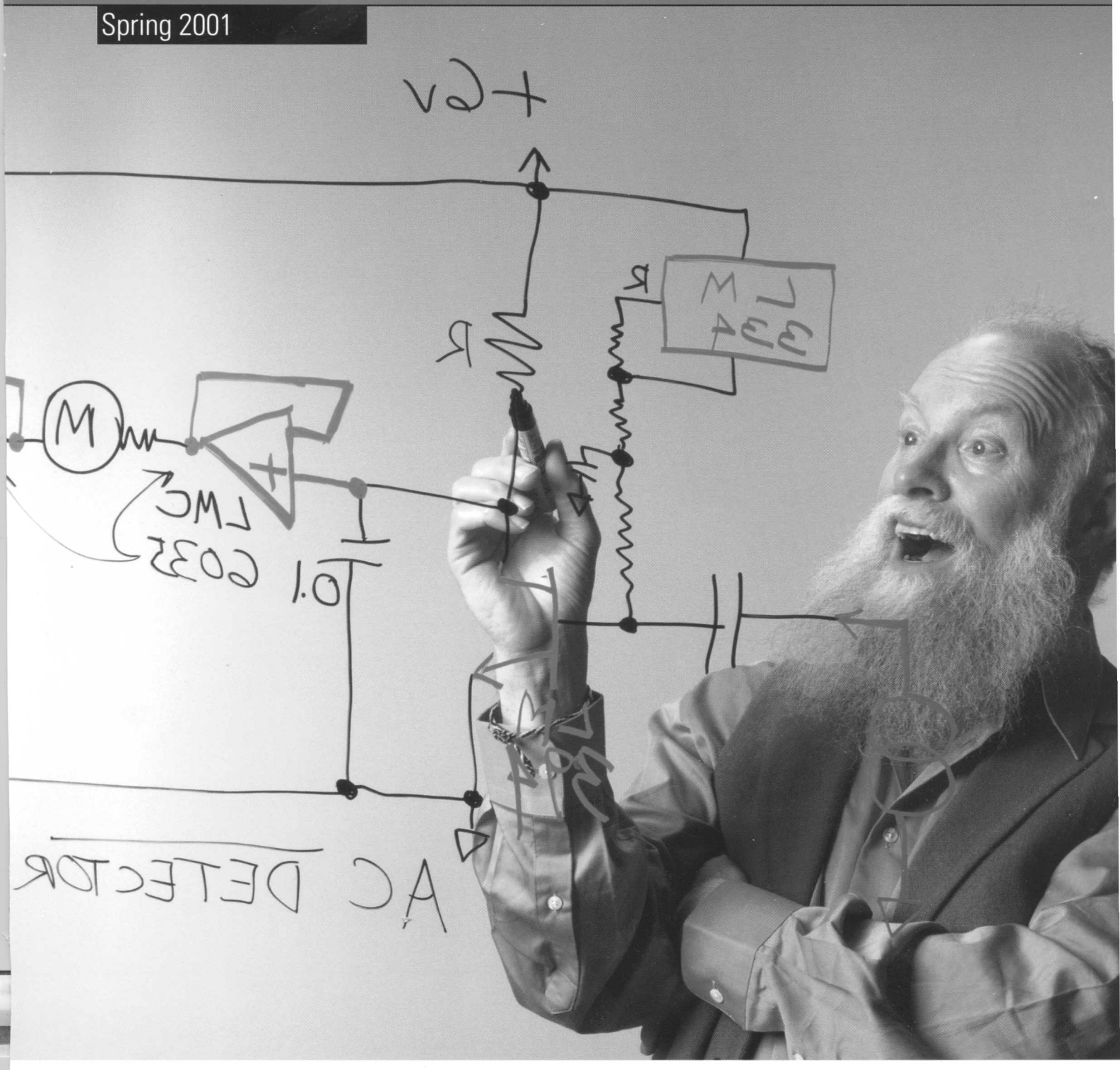
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Table of Contents

Section 1 High Speed Operational Amplifiers

CLC450 Photo-diode Amplifier 1 - 6

Differential Line Driving 1 - 11

LM7372 Differential Transmitter 1 - 16

ADSL Load Power Dissipation 1 - 22

New Amplifiers for Low Voltage 1 - 29

GSM Power Amplifier Control Loop 1 - 33

LMV248 Dual Band Controller 1 - 39

LMV7219 High Speed Comparator 1 - 42

Section2 WEB Simulation

POWER.NATIONAL.COM 2 - 7

Webench 2.0 Features 2 - 10

What's Behind WebSIM? 2 - 16

WebTHERM On Line Thermal Simulation 2 - 32

WIRELESS.NATIONAL.COM 2 - 51

Phase-Locked Loop Circuit 2 - 53

Create a Design 2 - 56

Appendix Technical Case Studies 2 - 69

Section 3 Power Management and Conversion

New Product Update and New Solutions 3 - 5

LM4140 Precision Reference Drifts Slower Than Grass Grows 3 - 9

LP3985, micro-LDO 3 - 14

LM3822 Current Sense Uses DS A/D Converter for Precision, Averaging 3 - 18

LM2612 Subminiature Buck Regulator for Handheld Electronics 3 - 21

LM2645 Set-Top Box Power Supply 3 - 26

LM3477 Step-Down 3.3V to 1.9V @4A 3 - 35

LM3478 3.3V to 5V Boost for I/O Card 3 - 38

Table of Contents *(cont.)*

Section 4 LVDS Devices for High Speed Interconnect

Bus LVDS features 4 - 4

DS92LV010A Signal Quality @ 100Mbps 4 - 8

Serialiser/deserialiser chipset 4 - 12

DS90CP22 Eye patterns @ 622Mbps 4 - 19

Section 5 Boomer™ Audio Amplifiers

Cell Phone Application Hints Improving PSRR 5 - 7

Cell Phone Application Hints Voice Band Filtering 5 - 12

Micro SMD PCB Layout Guidelines 5 - 19

LM4867 Boomer® Dual 2.1Watt with Stereo Headphone 5 - 31

LM4871 Boomer® **Higher Power** (3.0Watt) 5 - 36

LM4811 Boomer® Dual 105mW Headphone Amp with Digital Volume 5 - 38

Boomer® Family Summary Mono Output 5 - 42

Boomer® Family Summary Stereo Output 5 - 43

Section 6 Data Conversion Systems

LM98501 Camera AFE 6 - 4

LM9627 Color CMOS Image Sensor 6 - 8

ADC08060/ADC08100 8 bit 100MSPS ADC 6 - 14

ADC12040 12-bit, 40MSPS ADC 6 - 16

Tiny Package Temperature Sensors 6 - 32

LM20 Driving ADC Inputs 6 - 46

LM83 (RDTS) Typical Application 6 - 50

Reject Noise Even Further with Sigma-Delta ADC Architecture! 6 - 54

Section 7 Microcontrollers

Typical Analog Signal Processing System 7 - 3

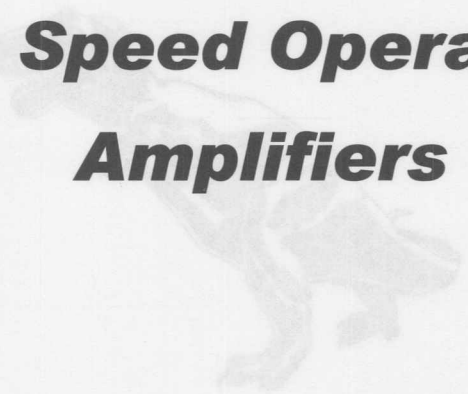
Amplified Temperature Measurement 7 - 7

COP8AME A/D-OpAmp Block Diagram 7 - 11

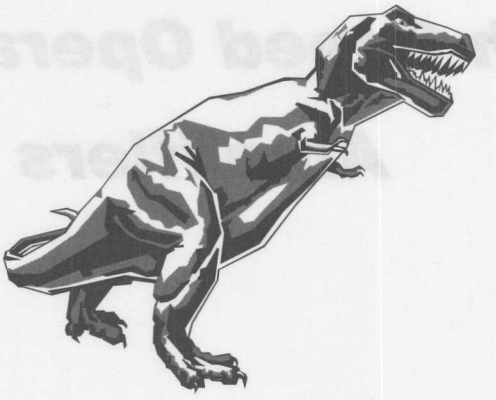
Analog System Development Challenges 7 - 13

National's 100% precise analog emulation 7 - 13

High Speed Operational Amplifiers



The Need for Speed



You need a High Speed Op-Amp, so how do you choose one? Well, turning to the selector guide section of your favourite semiconductor vendor's catalogue is one way. That way you will find that one manufacturer's definition of High Speed can be subtly different from another one. An alternative is to go on-line and use a parametric search...but if the search is too tight, you risk eliminating suitable devices that may be more easily available and less expensive than the offerings turned up by your search. On the other hand, the sheer breadth of the Op-Amp sections in many catalogues means a wider search won't necessarily narrow the choice down far enough.

Unfortunately, in the past, semiconductor manufacturers have not been too helpful in making it easy to choose an Op-Amp. Although a new Op-Amp may have improved characteristics for particular applications, the data sheet is written in such a way as to widen the potential applications for the Op Amp, so the manufacturer can enjoy increased sales.

This situation is unlikely to change in the future. Some high volume applications have resulted in Op-Amps specifically targeted for those applications, but the manufacturer remains alert to as yet unidentified opportunities.

Definitions & Parameters

Application Speed	100KHz to over 40MHz
Op-Amp GBW	10MHz to over 1GHz
f_{-3dB}	1MHz to over 400MHz
Small Signal	GBW, f_{-3dB}
Large Signal	Slew Rate, Settling Time
Differential Phase	0.05°
Differential Gain	0.05%

A further complication is that the way the user specifies the application does not necessarily match the way that the Op-Amp manufacturer specifies the Op-Amp. The user may think in terms of the maximum signal frequency involved and the amount of signal gain required (among other things), but for the Op Amp these two specifications are usually combined in a single parameter, the Gain BandWidth Product. While this reflects the universal nature of the Op-Amp, it also means that the impressive speed number on the front page of the data sheet diminishes rapidly in the real world application. For example, a 10MHz Op-Amp, used with a gain of 10, will have a -3dB corner frequency of 1MHz. For good signal fidelity (accurate gain and low distortion), the highest useable signal frequency is only 100KHz! Furthermore, at that signal frequency the maximum Op-Amp gain is only 100, a far cry from the impressive 100,000 to 1,000,000 probably quoted in the data sheet. To be fair, this situation exists because Op-Amps use global feedback, making the gain signal predictable and stable. On modern processes, amplifiers are built using local feedback, for significant gains at signal frequencies in the hundreds of megahertz range.

Sheer bandwidth is not the sole defining criterion for high speed, Op Amps are often used to process pulse waveforms where rise time and settling characteristics are important. In this connection, the terms "small signal performance" and "large signal performance" are not used to denote the actual size of the signal being processed, but to the differential input range over which the Op-Amp input stage remains linear. For "large signal operation" when the input differential signal is above a few millivolts, the output is slew limiting and the amplifier is open loop.

Other specifications seen on Op-Amps intended for video applications are "Differential Phase" and "Differential Gain". These help specify the small signal linearity of the Op-Amp.

Current Feedback

ALMOST UNLIMITED SLEW RATE

SIGNAL SOURCE IS CURRENT MODE

VERY LOW DISTORTION AT HIGH FREQUENCIES

There is one constant factor present in the development of new Op-Amps, the desire for improved performance (or decreased manufacturing cost). For much of the past three decades this has been done by the adoption of new fabrication technologies, with small changes in design topology. An Op-Amp user from the late sixties would find the current generation of Op-Amps quite familiar. That is not to say there hasn't been a search for new, radical topologies, but the almost overwhelming pressure to produce Op-Amps that are optimised for ease of use by the non-specialist has meant that modern Op-Amps are quite similar to those of thirty years ago. They run faster, draw less current, use lower supply voltages, but are fundamentally unchanged.

There is one exception. In contrast to the basic voltage feedback (VFA) topology of most Op-Amps, there is the current feedback (CFA) topology, pioneered into commercial practice by Comlinear. National, as well as other manufacturers, has a large number of CFAs in its Op-Amp portfolio. Even so this exception was driven in a large measure by the development of new fabrication technologies allowing complementary transistors to be built on the same process and since conventional VFAs can also be built on the new processes, this does not ease the choice between similar performing Op-Amps.

In general terms, a CFA should be considered when:

1) An almost unlimited slew rate is a key consideration.

In ATE a CFA is often a good choice as a pin driver. Fast rise times are obtained by driving the input harder and increasing the current available for slewing the output.

2) The original signal is in a current mode form.

The amplifier is used as a transimpedance amplifier. Also inverting mode operation from matching sources can have improved Noise Figures over non-inverting configurations.

& VOLTAGE FEEDBACK

EASE OF USE

LOW SUPPLY CURRENT

LOW CURRENT NOISE

MULTIPLE SOURCES

3) Distortion caused by high frequency components of the signal (harmonics) must be kept as low as possible.

This is perhaps the real advantage of the CFA's closed loop frequency response over a VFA. For any value of closed loop gain the CFA will have more loop gain available at high frequencies than the VFA with a comparable bandwidth. The fact that the CFA bandwidth changes relatively little as the closed loop gain is raised is not as important as most proponents of CFAs would believe. If the compensation capacitor of a VFA is decreased as the closed loop gain is increased then it, too, could maintain the closed loop bandwidth.

A VFA should be considered when:

1) Ease of use is important.

There are hundreds of Op-Amps available with thousands of well tried applications. Because the inputs of a CFA are not inherently symmetrical, applications such as an integrator function are not practical. Compensation techniques are slightly different and the differences need to be understood.

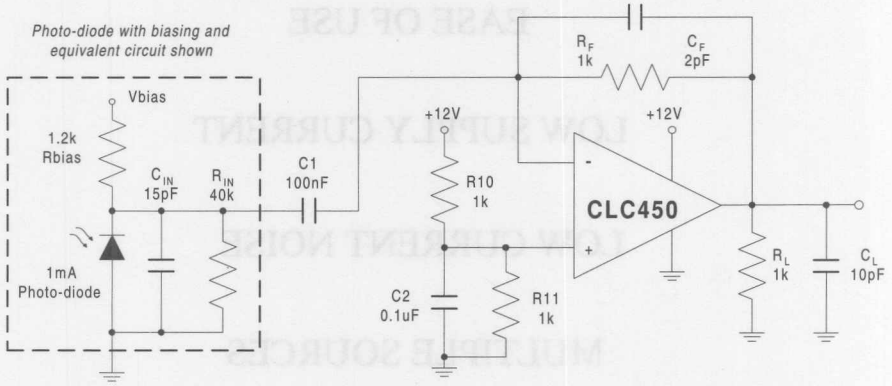
2) Least power consumption for a given speed of operation is needed.

For comparable bandwidths, a VFA can be designed to draw less supply current. The distinction can often be blurry, but these are general considerations anyway.

2) Current noise can be significant to the application.

Comparable CFAs will have 10 to 100 times the current noise of the VFA. Voltage noise is more in favour of the CFA, all other things being equal, and approaches that of the simple differential pair. A VFA will usually have lower input stage transconductance and uses emitter degeneration resistors for stability purposes.

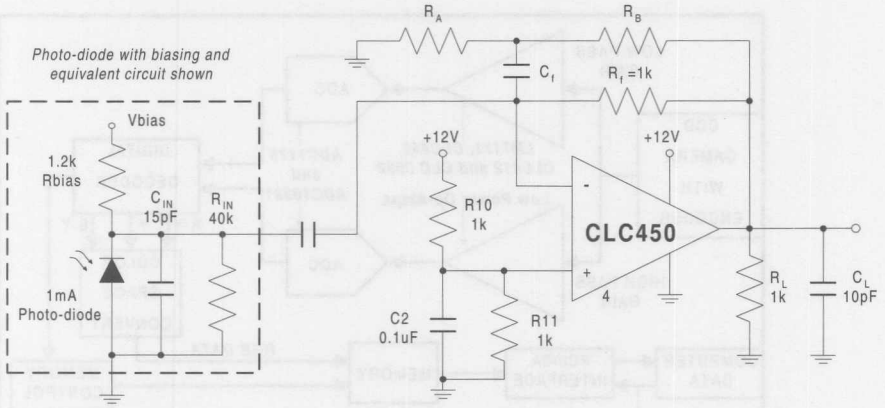
CFA Photo-diode Amplifier



A photo-diode amplifier is a good example of applying the strengths of the current feedback topology to the application. The input signal is a current and the required output is a voltage. Photo-diodes can present a significant capacitance at the input to the Op-Amp. The CFA has an effective internal buffer on the inverting node output impedance, producing a consequently low Ro, and the photo diode's output capacitance (Cin) introduces a zero in the Noise Gain at approximately $1/2\pi RoCin$. Compare this zero to that of a Voltage Feedback op amp in a similar configuration $[1/2\pi(Rin\|Rf\|Rbias)Cin]$ which tends to be much lower in frequency and more troublesome. This being the case, Cin has less of an effect on BW reduction and achieving stability is easier when using a CFA.

The example shown above is using the CLC450 (CFA). If Cin is sufficiently large, the closed loop phase shift will approach -180deg. at the cross-over frequency (where Open Loop Transimpedance Gain crosses the Noise Gain function). As with a VFA, the closed loop amplifier can be compensated by adding a small cap (Cf) across Rf. In this case, Cf was experimentally determined to be around 2pF for about 10% Overshoot in the Step Response. Cf improves stability by counter-acting the effect of the zero discussed in the paragraph above by introducing a low frequency pole ($1/2\pi RfCf$) and an inconsequential zero ($1/2\pi RoCf$).

Photo-diode compensation



Sometimes the capacitor value required for the desired level of overshoot, whether determined by calculation or empirically, is too small to be practical, as in the previous example. It is possible to change the required 2pF compensation capacitor to a more reasonable value, by adding RA and RB as shown above (voltage divider).

The new value of Cf is given by

$$Cf = (1+R_B/R_A)Cf$$

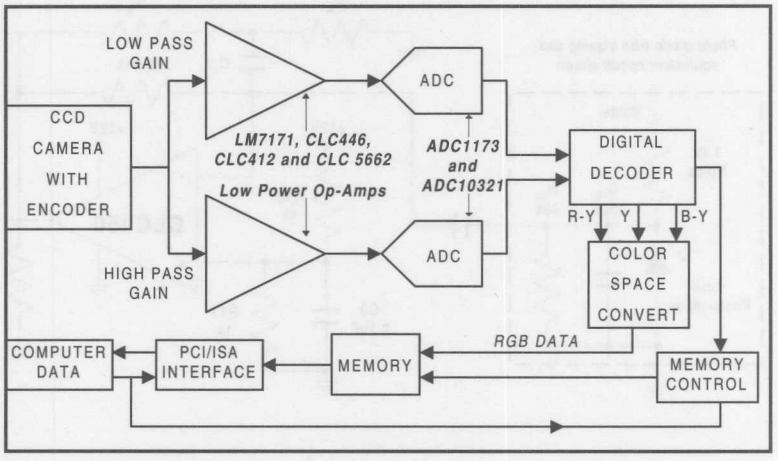
This relationship holds true as long as R_B<<Rf, so selecting R_A=50Ω and R_B=500Ω

$$Cf = (1+500/50)2pF = \sim 22pF$$

which is a much more practical component value.

This value needs to be "fine tuned" in the real application for proper step response.

Video Applications

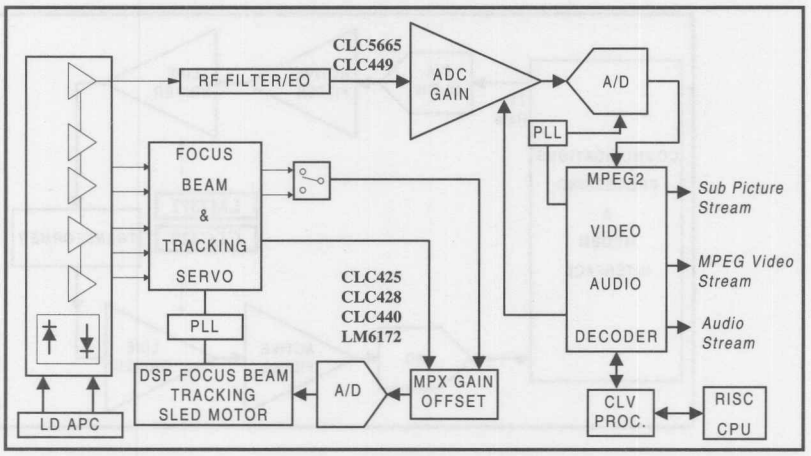


Apart from the more obvious Op-Amp applications as video buffers for cable drivers, high speed Op-Amps can be used in camera systems (and scanners) to buffer the signal from the CCD into the D/A converter.

Useful devices for both luminance and chrominance channels are the LM7171, CLC446, CLC412 and the CLC5602. Differential Gain and Phase numbers can be as low as 0.02% and 0.02° respectively for these parts. These specifications are arrived at by applying a small high frequency signal to the amplifier (3.58MHz or 4.43MHz) and varying the dc level of this waveform through the entire common mode input range. Any deviations in amplitude or phase of the waveform at the amplifier output are recorded, with the maximum deviation resulting in the DG/DP numbers for the amplifier.

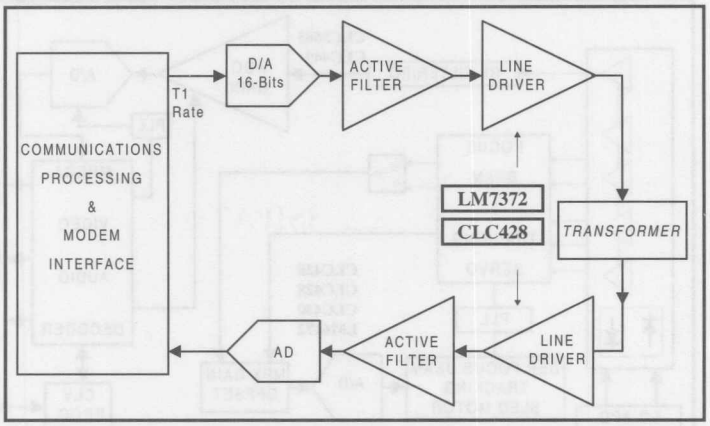
In this application, the amplifiers are driving the ADC1173, 8 bit, or ADC10321, 10 bit converters. Both these converters offer at least 3dB better S/N than competitive devices in the 8-10bit category.

High Speed, High Resolution



Similar to the previous example, the Op-Amps are used to drive high speed converters, again 8 to 10 bits at up to 20MSPS, and in the 12 to 14 bit range for motor control purposes with update rates from 2.5MHz to 10MHz. The CLC5665 can maintain a gain flatness of 0.1dB over a 20MHz frequency range with a slew rate of 1200V/us. The CLC449 has an even higher slew rate of 2500V/us. For motor control the servo speed CLC425,428, 440 and LM6172 are appropriate.

Communications



For the increasingly popular xDSL systems, high speed Op Amps are used to drive the upstream signal through the copper wires, and to amplify and buffer the down stream signal to the modem. Although high speed is necessary, despite relatively low data rates, other parameters are important.

On the receiver side, low noise is important to maximise the dynamic range, and the CLC425, 428 and CLC440 have input referred noise voltages as low as $2nV\sqrt{Hz}$. As a dual the CLC428 is well suited for the differential receiver function and offers very tight matching between the two amplifiers. The LM6172, also a VFA dual, has the same high GBW (100MHz) and a slew rate of 3000V/us.

On the transmit side, high output current and voltage swing capability is important in addition to low distortion. The LM7171 single has a GBW over 200MHz and is able to deliver 100mA signal currents into 100Ω loads. The newly introduced LM7372 is a dual version that can deliver even more load current, 150mA, at similarly low distortion levels.

Differential Line Driving

HIGH SPEED/LOW DISTORTION

BRIDGE AMPLIFIERS

POWER DISSIPATION

PACKAGING/HEATSINKING

The xDSL modem application is worth studying in greater detail, since it combines many elements of a high speed Op-Amp application that need to be addressed, other than selecting an Op-Amp that "just seems fast enough".

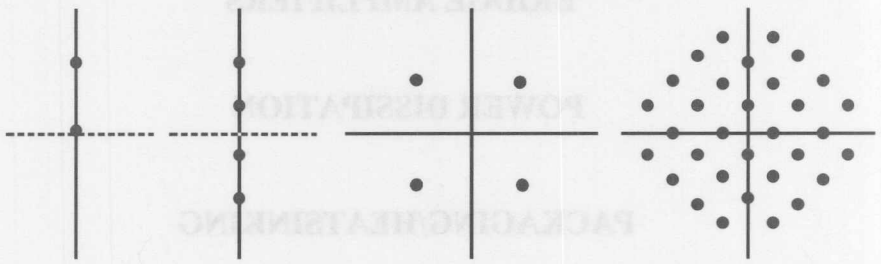
Although the transmit highest frequency is no more than 100KHz at the CPE (Customer Premise End) modem, and barely over 1MHz at the CO (Central Office) end, Op-Amps that are suitable for line driving will have GBWs in excess of 80MHz. The differential character of the twisted copper pair requires two amplifiers connected in a "bridged" mode, so that output voltage swings are substantially larger than the supply voltage available to the modem. The delivered power is only 20mW, but the internal power dissipated by the Op-Amp can be a factor of 25 or more times higher, requiring the circuit designer to consider different topologies to help minimise this power dissipation. The modern trend to packages with ever smaller footprints exacerbates the heat dissipation problem, since many surface mount packages are not amenable to effective heatsinking.

The following pages will examine an application specific example for xDSL, but because the design conflicts are common to many high speed designs, hopefully this will show directions that can be taken to provide solutions to a wide variety of designs.

xDSL

x Digital Subscriber Loop/Line

x = A Asymmetric DSL
= S Symmetric DSL
= V Very High Bit Rate DSL
= RA Rate Adaptive DSL
= H High Speed DSL

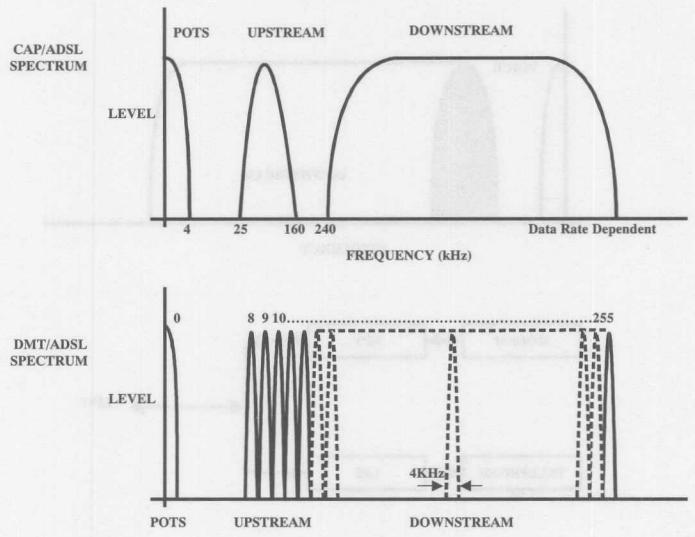


BINARY 2BIQ 4 Level QAM 32 Level QAM

Other than forcing the circuit designer to become familiar with a whole new set of acronyms, xDSL (standing for Digital Subscriber Loop/Line, with the x representing the various flavours of DSL) enables broadband communication into small businesses and residences via the the twisted copper pair that provides the traditional voice telephone service or POTS (Plain Old Telephone Service). Originally conceived in the early nineties as a means for providing VOD (Video On Demand) in competition with cable providers, the explosive growth of the Internet in the late nineties has resurrected DSL as a viable means to transmit and receive digital data through existing phone lines.

The impedance/frequency characteristics of the twisted copper pair means that some form of data compression is required in order to reach acceptable data rates. Most of these modulation schemes are based on a variation of QAM (Quadrature Amplitude Modulation). Instead of simple binary (a string of ones and zeros), a carrier is modulated in amplitude and phase. With a single carrier phase, modulating the amplitude by two levels doubles the transmission efficiency, 2B1Q. This is the basic modulation scheme used in DSL. Using more carrier phases and amplitudes produces more complex constellations for even higher data rates, at the risk of more susceptibility to interference.

ADSL with CAP & DMT

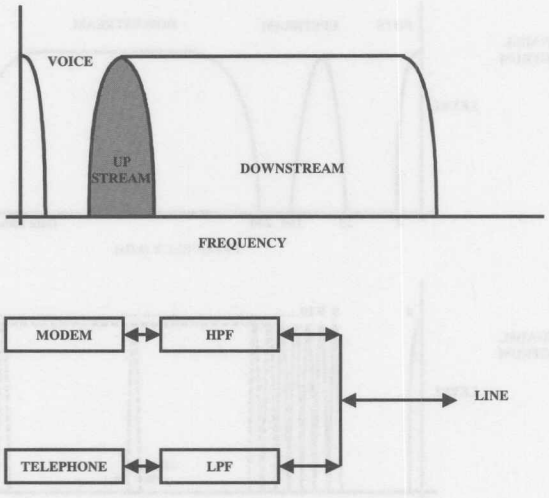


The spectrum of ADSL with CAP is shown above. For the downstream data channel two carriers at the same frequency but with a 90° phase difference, well above the voice baseband signal, are each modulated with a number of levels. The bandwidth occupied by this signal depends on the number of levels used (between 4 and 512) giving data rates of around 1.5MHz on long loops to as much as 8MHz on short loops. A similar modulation scheme is used for the upstream carrier but with a lesser number of levels being used for an occupied bandwidth between 25KHz and 160KHz. Because the impedance/frequency characteristic of the copper pair is so variable, CAP uses adaptive equalisation. At startup there is a 'training' phase to identify the individual line characteristic. Since this equalisation is over a 50dB dynamic range, extensive number crunching is needed.

ADSL with DMT takes a slightly different approach. Instead of single carrier frequencies, DMT divides up the available spectrum into 256 subchannels, each 4KHz wide. The space for the 8 lowest subchannels is left open for the POTS system, as with CAP. The remaining subchannels can each be modulated with up to 15 bits of data so high data rates are achieved by using more subchannels. Depending on the system, the lower 32 of the occupied subchannels are used by both the downstream and upstream signals, with echo cancellation separating the signals in the area of overlap. Other systems sacrifice a little of the downstream rate by reserving the lower subchannels for the upstream signal exclusively.

The assumption with DMT is that the line characteristic will not change much in a narrow 4KHz bandwidth and adaptive equalisation is not needed. Nevertheless, the extensive Fourier transform calculations to reconstruct the signal from the useable subchannels involves an equal amount of number crunching.

ADSL & NEXT

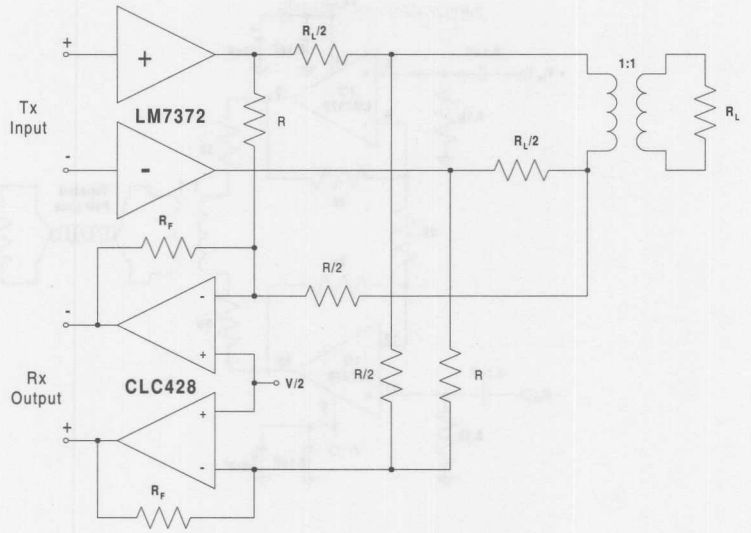


As the title ASDL says, the bandwidth allocated to the downstream and upstream channels is asymmetric. For most residential applications the slower upstream data rate is considered acceptable since it is anticipated that the amount of download will always be much larger than the upload from the CPE. More importantly, this asymmetric arrangement helps to minimise the effects of Near End Cross Talk, or NEXT. A large number of copper pairs are bundled into each telephone cable, and if the same bandwidth was occupied for both upstream and downstream transmissions, then an adjacent strong upstream transmission could easily interfere with the much weaker downstream transmission, particularly as the distance from the CO increases.

Installation of the CPE modem is not as easy as most people would want. Many installations require a splitter to separate the voice/fax/analogue modem traffic from the DSL modem traffic and vice versa. The high pass filter protects the modem from the POTS, but also helps to prevent low frequency side lobes from the modulation process increasing the noise floor in the voice channel. Similarly the low pass filter protects the POTS channel from the 30KHz and up signals from the DSL modem, and simultaneously shields the modem from the many non-linear impedances that are present on the POTS line.

Splitter-less DSL (G-Lite for example) eliminate one of the filters, the low pass, by reducing the transmit power of the DSL modem by 75% so that, in the absence of the LPF, interference to the POTS channel is kept at acceptable levels.

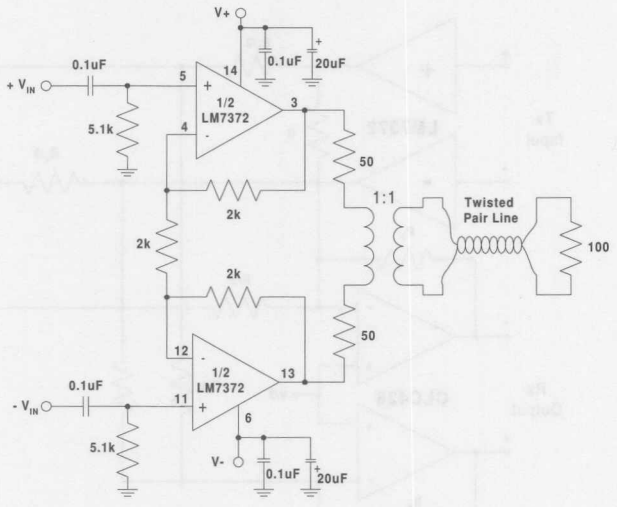
The ADSL Transceiver



A typical ADSL transceiver will look as shown here in this simplified schematic. Note that the output of each transmitter Op-Amp drives a terminating resistor to match the line impedance of 100Ω. With a 1:1 transformer turns ratio these terminating resistors will be 50Ω each.

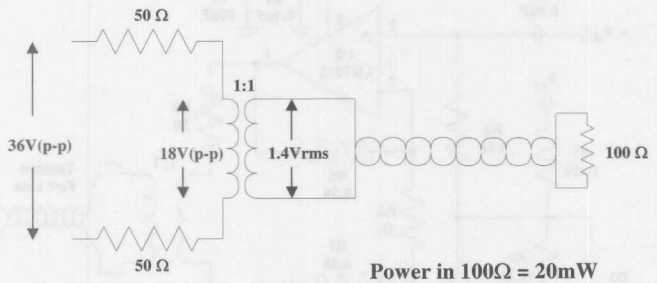
The receiver Op-Amps are used in an inverting gain mode so that with the resistor ratios shown, there will be a first order cancellation of the transmitter signal at the receiver inputs. If a different transformer turns ratio is used, particularly with lower supply voltages, in order to obtain sufficient transmitter voltage swing on the line, the resistor ratios will change correspondingly. While stepping up the output swing with a higher turns ratio makes it easier for the transmitter, it does mean that the received signal will be attenuated by a like amount.

LM7372 Differential Transmitter



Here is a more detailed view of the transmitter section, using the high speed, high supply voltage dual LM7372 Op-Amp. This is a differential input to differential output topology, with a split 24V supply voltage. While a split supply avoids the need for input bias networks, there are other consequences to using split supplies, particularly with regard to heatsinking, which we will cover later. The LM7372 is stable with non-inverting gains as low as +2 as shown here. This gives the widest bandwidth and lowest distortion but higher gains are generally used (between 5X and 8X, to get sufficient output swing to meet the DSL drive specification. On the other hand, having more signal gain than necessary is not recommended, since higher gains will reduce the available loop bandwidth at high frequencies. A good rule of thumb is to keep the closed loop bandwidth close to 10X the highest signal frequency. The pin numbers given are for the LM7372 in a SOIC 16 package.

Power and Swing for DMT



Power in 100Ω = 20mW

Average voltage = 1.4Vrms

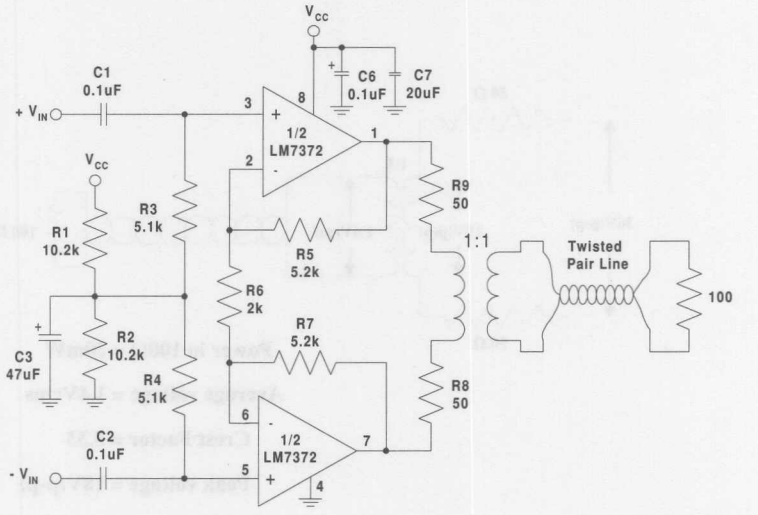
Crest Factor = 5.33

Peak voltage = 18V(p-p)

At first sight the output swing and power requirements for the DMT modulated DSL signal appear to be very modest. At the CPE end, the transmitter must put an average power of 13dBm onto the copper pair which is assumed to have a characteristic impedance of 100Ω. This translates to 20mW on the line. Since each amplifier has to drive the terminating resistor as well as the load, then each amplifier will have to deliver 20mW for a total of 40mW. The average output voltage swing is 1.4V, or 4V(p-p) which is well within the capability of an Op-Amp running on a 12V supply.

Unfortunately, in the real world, things are not as simple. The specification is for the average power delivered to the load. A DMT modulation uses a large number of frequencies to transmit high data rates, and at any time the phase and amplitude of the individual tones will be such as to generate a combined signal amplitude with a higher instantaneous or peak value than 4V(p-p). For DMT the crest factor is assumed to be around 5.33, for a peak value of 15V(p-p). Add to this a little headroom for transformer losses (0.5-1.0dB) and the voltage drop across the terminating resistors, the transmitter output must be capable of swinging up to 36V(p-p). This looks to be far more than an Op-Amp can handle, even with a 30V supply.

Single Supply Differential Drive

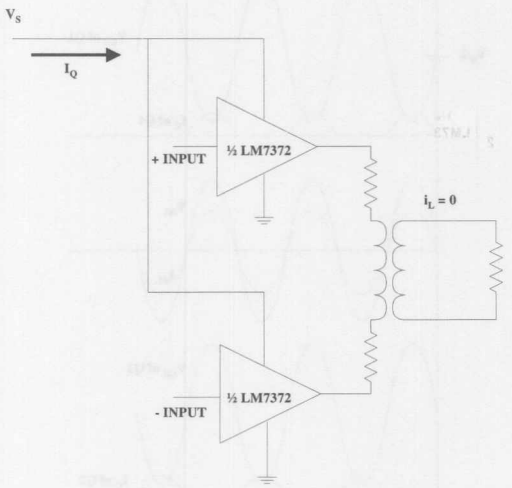


This is where differential or bridge drive enters the picture. By using two amplifiers to process the input signal, but with one input reversed in phase from the other, as one amplifier swings positive by 18V the other swings negative by 18V. The net result is a load swing of 36V even though the amplifiers are operating with a supply voltage sufficient to support an 18V swing. A 24V supply ensures adequate headroom for peak signal swings with low distortion. The bias network of R1 and R2 places the dc voltage of the non inverting inputs at +12V. The pin numbers are for an LM7372 in the LLP-8 package.

As noted earlier, larger signal swings are possible by increasing the transformer turns ratio.

For a 12V supply, a 2:1 turns ratio will give the necessary load swing, but now the peak current from each Op-Amp is doubled.

Power Dissipation



$I_Q = 13mA$

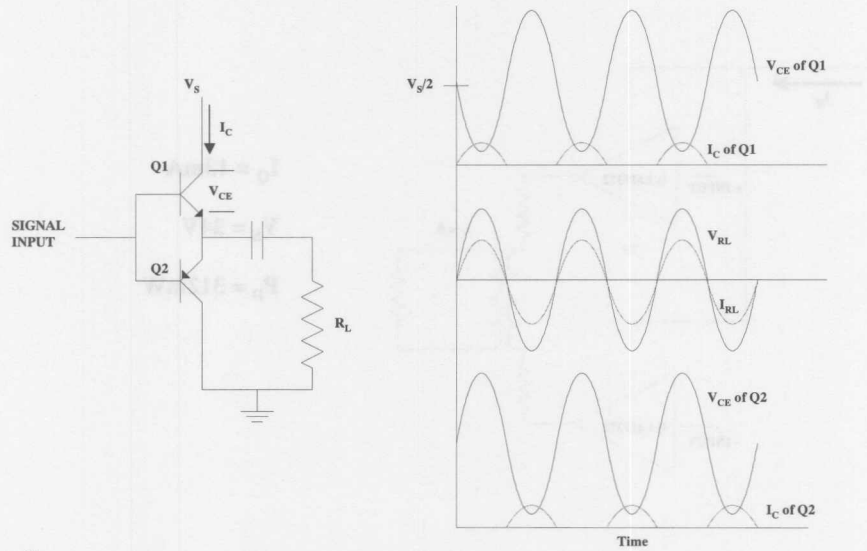
$V_S = 24V$

$P_D = 312mW$

For many Op-Amp applications, power dissipation is not very often an issue. For high speed applications it is. Generally an Op-Amp designed for good performance at high frequencies will have bias currents of several milliamps. At low supply voltages with light loads, the power dissipation can be low, but as the signal swing goes up, requiring higher supply voltages, and the load impedance decreases to the order of 100Ω or less, then the power dissipation can be a significant factor in the design. Power dissipation has several impacts other than requiring larger power supplies. If a lot of the circuits in an enclosure are dissipating heat (a DSLM for example), then the temperature within the enclosure may be driven higher than acceptable. Ventilation or forced cooling can be necessary at high ambient temperatures. For the individual I/C within the enclosure, this temperature rise, coupled with the higher junction temperature caused by internal power dissipation, may take the device out of the range specified by the I/C manufacturer, degrading performance and reducing reliability.

There are two major components of power dissipation that contribute to the Op-Amp's internal junction temperature. The first is the quiescent supply current which is present when no power is being delivered to the load. Usually for a given supply voltage, this component of power can easily be calculated from the data sheet parameters for the I/C, even at elevated ambient temperatures. For the LM7372, the quiescent supply current is listed as 13mA (using both amplifiers). With a 24V supply, therefore, the quiescent power dissipation is 312mW. At elevated temperatures the worst case dissipation will be higher, but for the moment we will stay with this number.

Class B Waveforms



The second component, that of additional power dissipated within the I/C while delivering power to the load, is not so easily calculated, and empirical measurements may be necessary.

The majority of Op-Amps use a form of the Class B output stage topology, and this is where the power is dissipated when the amplifier is driving the load. Dissipation in either transistor is the product of the collector to emitter voltage and current. For one half of the load cycle Q1 is conducting, for the other half Q2 is conducting. Notice that in either case, during conduction as the collector to emitter current goes up, there is a corresponding fall in the collector emitter voltage. This means that during the early part of conduction, power dissipation will increase with load current, but as the collector emitter voltage approaches zero, the power dissipation will go down again.

Calculating the Power Dissipation

$$V_{CE} = V_S - (V_S/2 + V_L \sin\omega t) = V_S/2 - V_L \sin\omega t$$

$$I_{EC} = V_L \sin\omega t / R_L$$

$$p_D = (V_S/2 - V_L \sin\omega t) \times V_L \sin\omega t / R_L$$

$$P_D = (1/2\pi) \int_0^{\pi} (V_S/2 - V_L \sin\omega t)(V_L \sin\omega t / R_L) d(\omega t)$$

$$P_D = (1/\pi) \int_0^{\pi} (V_S/2 - V_L \sin\omega t)(V_L \sin\omega t / R_L) d(\omega t) \quad \textit{(both transistors)}$$

$$= (V_S V_L / 2\pi R_L) \int_0^{\pi} \sin\omega t \, d(\omega t) - (V_L^2 / 2\pi R_L) \int_0^{\pi} (1 - \cos 2\omega t) d(\omega t)$$

$$= (V_S V_L / 2\pi R_L)(2) - (V_L^2 / 2\pi R_L)(\pi)$$

$$\boxed{P_D = V_S V_L / \pi R_L - V_L^2 / 2R_L}$$

With a power supply V_S and a load voltage swing V_L

$$V_{CE} = V_S - (V_S/2 + V_L \sin\omega t) = V_S/2 - V_L \sin\omega t$$

$$I_{EC} = V_L \sin\omega t / R_L$$

and the transistor instantaneous power is given by

$$p_D = (V_S/2 - V_L \sin\omega t) \times V_L \sin\omega t / R_L$$

To find the average power we integrate this expression over the half cycle for which the transistor is conducting.

$$P_D = (1/2\pi) \int_0^{\pi} (V_S/2 - V_L \sin\omega t)(V_L \sin\omega t / R_L) d(\omega t)$$

For the other half cycle the other transistor dissipates the same power, so for the complete output stage the average power dissipation is given by

$$P_D = (1/\pi) \int_0^{\pi} (V_S/2 - V_L \sin\omega t)(V_L \sin\omega t / R_L) d(\omega t)$$

$$= (V_S V_L / 2\pi R_L) \int_0^{\pi} \sin\omega t \, d(\omega t) - (V_L^2 / 2\pi R_L) \int_0^{\pi} (1 - \cos 2\omega t) d(\omega t)$$

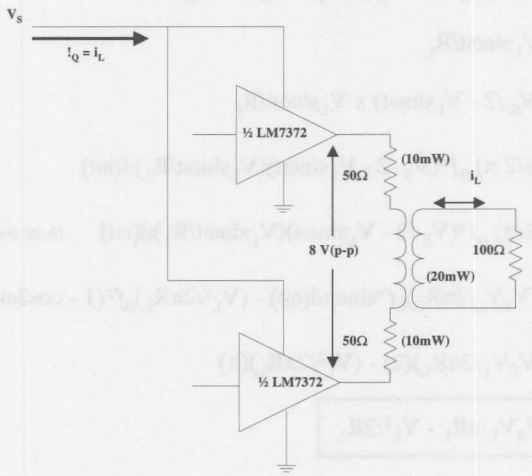
$$= (V_S V_L / 2\pi R_L)(2) - (V_L^2 / 2\pi R_L)(\pi)$$

$$= V_S V_L / \pi R_L - V_L^2 / 2R_L$$

The second term in the above expression represents the power that is actually delivered to the load.

N.B Taking the second derivative of the expression for power dissipation and equating that to zero will show that the maximum internal power dissipation will occur when the load swing is 63.7% of the supply voltage.

ADSL Load Power Dissipation

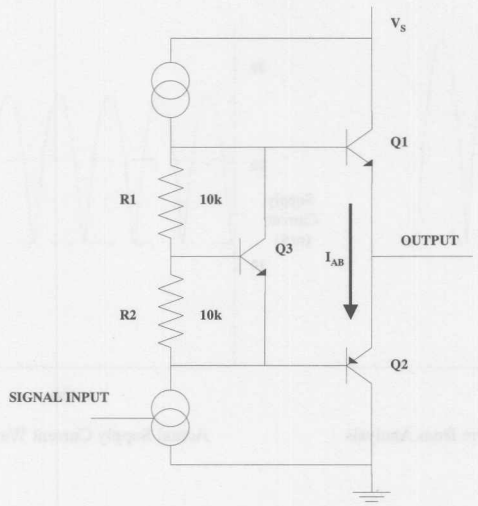


The previous expression is useful for giving a first order approximation to the potential power dissipation in many applications, although it assumes a sine waveform.

Returning to the DSL transmitter, if the average load power is 20mW, V_L is 2V(peak) and substituting this value back into the equation with a 100Ω load gives the average power dissipation for each amplifier as 133mW. With a quiescent power dissipation of 312mW the total package power dissipation has risen to 578mW---- all for a delivered power of 20mW!

Most 8 pin surface mount packages have thermal resistance that is well over 100°C/Watt. With this level of internal power dissipation, an SO8 package with a θ_{JA} of 140°C/Watt, at an elevated ambient temperature of 85°C will have a junction temperature of 166°C, certainly above the manufacturer's absolute maximum rating. Even though semiconductor manufacturers can offer "thermally enhanced" SO packages, some form of heatsinking is going to be necessary, and this needs consideration in the early pcb development stages. Getting a good idea of what the power dissipation level actually is, means a board can be designed with a healthy safety margin at least cost.

The VBE Multiplier



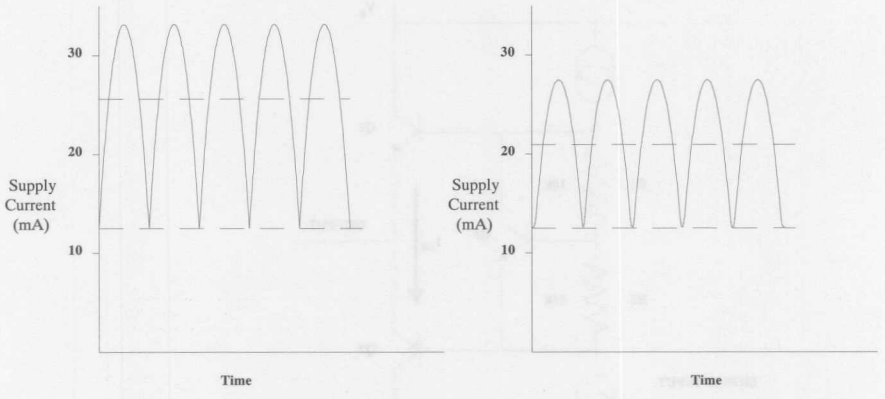
Before moving on to determine the size of heat sink required, let us take another look at that Class B output stage. In the analysis, we assumed that while one transistor was conducting the other transistor was completely off. The transition of conduction from one to the other occurs as the load waveform passes through Vs/2. For the simplified schematic shown, with the bases of both transistors connected together, this would indeed be the case. In fact there would be a dead zone, approximately 1.4V wide (2 base-emitter diode drops), during which neither transistor would be conducting. This gap in the load current causes high levels of cross-over distortion and would be disastrous for most applications.

Cross-over distortion is avoided by using a bias network similar to that shown here. The transistor base emitter diode sets the voltage across R2 to approximately 0.7V. Therefore the current flowing in R2 is 100uA. Except for a small amount of base current, this same current must be flowing in R1, so the collector-base voltage is also 0.7V. This places the total voltage across the transistor at 1.4V, thus compensating for the output stage diode drops.

To minimise crossover distortion, the value of R2 is set to give a certain level of current conduction in the output stage even when there is no load current. For the LM7372 the AB bias current is 3.3mA.

The significance of this is that part of the LM7372 quiescent power dissipation comes from this AB bias current. As the output load current increases from zero, this bias current is diverted into the load. Above 3.3mA load current, all of the bias current is appearing as load current. Therefore to assume that the average power dissipation is the sum of the quiescent and load power dissipation is incorrect.

Bias Current added to Load



Supply Current Waveform from Analysis

Actual Supply Current Waveform

The average current for a load power of 20mW is 14.1mA. If we neglect the contribution of the AB bias current to the load current, the total current appears as the peak value of the load current, $\sqrt{2}$ x 14.1mA or 19.9mA, superimposed on the quiescent current of 6.5mA.

However when we add the AB bias current to the load current, the supply current swing is only 14mA instead of 19.9mA. Now the average value of the supply current is 21mA.

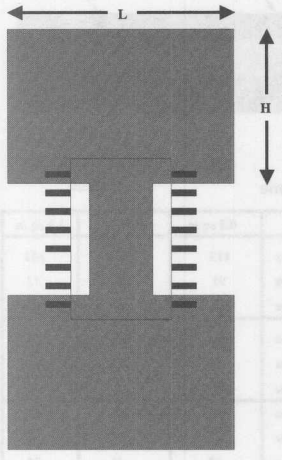
$$P_D = (V_S \times I_{AVG}) \text{ - Power in Load}$$

$$= (24 \times 21)\text{mW} - 40\text{mW}$$

$$= 464\text{mW}$$

This level of power dissipation in a standard SO8 package would not push the junction temperature above the absolute maximum (barely) at elevated ambient temperatures, but there is no margin to allow for component tolerances or higher than expected signal levels.

SOIC 16 Package



L (in)	H (in)	θ_{JA} (^{0}C/W)
1.0	0.5	83
2.0	1.0	70
3.0	1.5	67

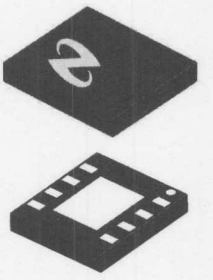
For reasons of reliability, we would like to keep the maximum average junction temperature in the 110°C to 120°C range or even lower. With a power dissipation of 464mW and an ambient temperature of 85°C, this means a total package thermal resistance in the range of 60°C/W to 80°C is needed for this application.

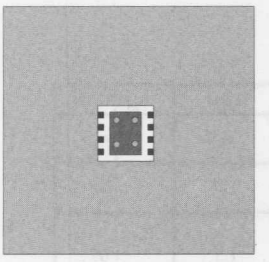
Most Op-Amp surface mount packages, SO8, SO14, SO16 etc have free air thermal resistances much higher than this, but special package variants are available that allow the heat to be removed from the package and dissipated by an area of pcb copper.

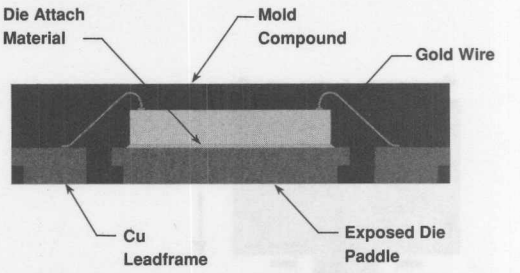
One such package is the SOIC 16. For a dual Op-Amp, only 8 pins are needed, so for the SOIC 16 the end pins of the package are connected to the leadframe. The I/C substrate is attached to the die attach paddle and heat transfers out via these four connections.

Using a "dog bone" area of copper reduces the thermal resistance into the range required. For a θ_{JA} of 70°C/W a total area of 4 square inches (2600mm^2) of 1 oz copper is sufficient.

LLP Package







Copper Area		0.5 sq in	1.0 sq in	2.0 sq in
Top Layer Only	0.5 oz	115	105	102
	1.0 oz	91	79	72
	2.0 oz	74	60	52
Bottom Layer Only	0.5 oz	102	88	81
	1.0 oz	92	75	65
	2.0 oz	85	66	54
Top and Bottom	0.5 oz	83	70	63
	1.0 oz	71	57	47
	2.0 oz	63	48	37

Thermal Resistance (^{0}C/Watt)

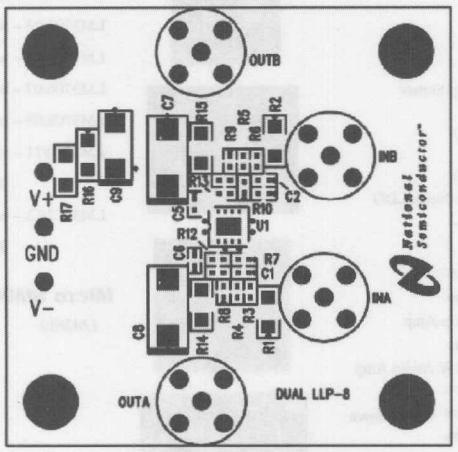
National Semiconductor

Analog Applications 26

A new package from National is the LLP, which has no leads external to the package. This package also has the lower surface of the die attach paddle exposed. Heat from the die flows directly through the paddle to the surface of the pcb. Board copper area used for heat sinking with this package is much more effective as the table above shows. With heat vias to the bottom layer, the same two square inches of 1 oz copper reduces the thermal resistance to 65°C/W. Using the top layer as well, with 2 oz copper, the thermal resistance can be as low as 37°C/W.

With this package, and the previous package, it should be remembered that the copper used for heat sinking will be at some electrical potential. This will be the chip substrate potential which for these technologies will be ground on a single supply, or V- on a split supply. For the SOIC 16 the copper area will be usually on the top or component side. For the LLP8, the use of vias puts the heat sink copper on the bottom or ground plane side, making for an easier layout.

LM7372 Test Board



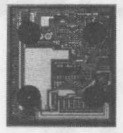
Some test boards for the LM7372 in both the SOIC 16 package and the LLP-8 package are available. Shown here is the LLP-8 board populated as a DSL driver. The board can be reconfigured for single ended amplifiers in both inverting and non-inverting gains.

Note that the top copper underneath the package extends out beyond the ends of the package. The two extra vias two the bottom layer at each end are used for added heat sinking if necessary.

New microSMD Devices Since 1999

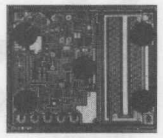
Micro SMD-4

LM20 - Analog Temp Sensor
LM431 - Shunt Reg



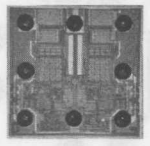
Micro SMD-5

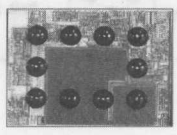
LM74	- Analog Temp Sensor
LP2980	- 50mA LDO
LP2981	- 100mA LDO
LP2982	- 50mA LDO
LP2985	- 150mA LDO
LP3985	- 150mA Low-Noise LDO



Micro SMD-8

LMC555	- CMOS Timer
LMC6035	- Dual Op Amp
LMC8101	- High Drive Op Amp
LM358	- Dual Op Amp
LM4820	- Fixed Gain 1W Audio Amp
LM4872	- 1W Boomer™
LM4877	- 1W Boomer™ w/ shutdown
LM4878	- 1W Boomer™
LM4890	- 1W Cellular Audio Pwr Amp
LP2967	- Dual 150mA LDO





Micro SMD-9

LM3700/01 – mP Supervisory Circuit Low Line Output
LM3702/03 – with manual reset
LM3704/05 – w/ manual reset and Power Fail Input
LM3706/07 – with Watchdog Timer Output
LM3708/09 – w/ Watchdog Timer Output and Manual Reset
LM3710/11 – w/ Power Fail Input, Low Line Output, Manual Reset and Watchdog Timer
LM3712/13 – w/ Separate Watchdog Timer Output, Power Fail Input and Manual Reset

Micro SMD-10

LM2612 - Programmable,Step-Down DC-DC Converter

National Semiconductor

Analog Applications 28

During our previous seminar series in 1999, we introduced the microSMD package with the world's smallest dual Operational Amplifier, the LMC6035. Since that time we have introduced many more devices in the microSMD package as listed here….and the list continues to grow.

Low Power Consumption

Low Voltage

Operational Amplifiers



Along with all the developments in high speed amplifiers, we have continued to fill in the low voltage, low power consumption operational amplifier functions in our portfolio. This next section will cover some of our activities in LV/LP.

A short historical note:

About 15 years ago the most popular processes for Op Amps were bipolar. Then, as portable equipment became more popular there was a shift to CMOS, and what people called Low Power amplifiers. This was actually meant to signal a need for reduced power consumption and many assumed CMOS would be the process of choice. Although this has happened, ironically it is not because CMOS is inherently low power…that comes about because in digital systems the CMOS transistor is either off (I), with voltage across it but no current drain, or on (0) with current drain but no voltage across it. When a CMOS transistor is used in the analog world, working between fully on or off, it draws as much if not more current than an equivalent bipolar transistor. These early amplifiers really had low performance at low supply current levels. The real gain realised by going to CMOS was a reduction in manufacturing cost (smaller die and less than half the processing steps) and the fact that, with common drain outputs, the CMOS device can be swung almost to the supply rails. CMOS ushered in the era of Rail-to-Rail amplifiers.

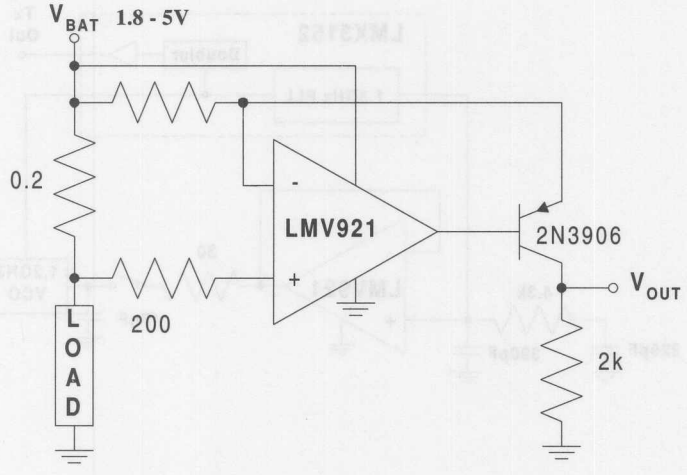
New Amplifiers for Low Voltage

- Bipolar
- Low power
- CMOS
- Rail to Rail
- Single Supply

Today we are able to offer amplifiers that draw very little supply current, yet have respectable bandwidths and slew rates, using a combination of bipolar and CMOS processes. Rail-to-Rail outputs have become the norm, primarily to ensure good swing capability on on low voltage supplies. Rail-to-Rail capability will depend on the load current, and careful note should be made of the load used for the measurement when comparing amplifiers. Typically, any amplifier whose outputs get within less than 600mV of the rail with a given load, are considered Rail-to-Rail. For light loads, within 10mV of the rails is possible.

Rail-to-Rail inputs are less prevalent than Rail-to-Rail outputs. An amplifier operated in the inverting mode doesn't need common mode range or swing at the input. Many amplifiers are offered as single supply amplifiers, meaning that the inputs can be operated at either of the supply rails but not both. Ground is usually chosen as the reference. Nevertheless, Rail-Rail inputs are being asked for, whether needed or not, and are likely to become a standard feature in low voltage amplifiers. For most amplifiers in this category, the input common mode voltage actually extends beyond the rails, by about 300mV.

Positive Supply Rail Current Sense

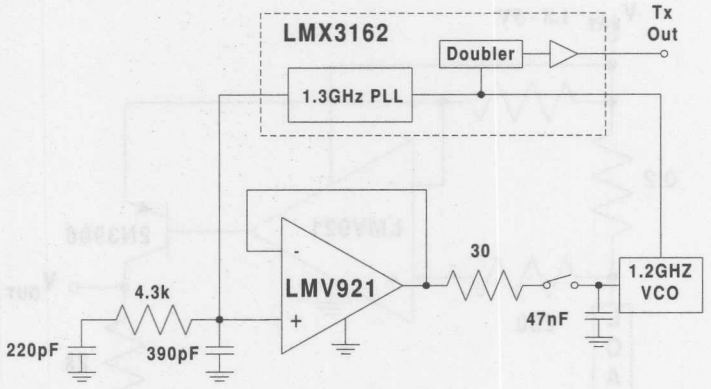


One place where operation at the positive rail proves useful is in current sensing. Nearly any single supply Op Amp could be used for sensing current by the voltage drop across a low valued resistor in series with the ground lead of the load being sensed. However in this arrangement changes in load current will mean there will be changes in the ground potential. If the sense resistor is placed in the power supply lead, then the Op-Amp will be handling input signals at or very close to its own supply voltage.

In this circuit, current flowing through the sense resistor will cause a voltage difference to be applied to the inputs of the Op-Amp. The lower voltage at the non-inverting input will cause the Op-Amp output to pull the base of Q1 low, in turn causing an increased current flow through the upper 200 ohm resistor. The output voltage will stabilise when the current drop in this resistor matches that across the sense resistor. With the values shown, Q1 output will shift by 2 Volts for a 1 Amp shift in load current.

The LMV921 is the single Op-Amp in a 1MHz, RR I/O, 1.8V to 5V supply family, and is available in the SC70-5 package.

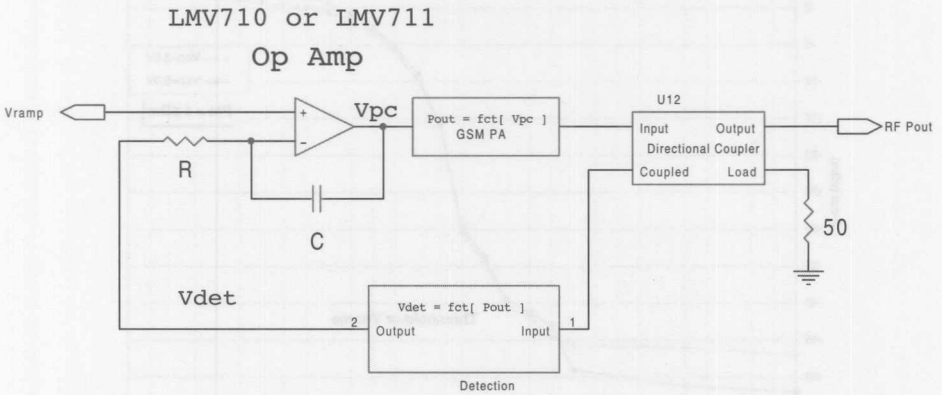
Ultra Low Drift PLL



In the unlicensed ISM band, half-duplex TDMA systems are employed (HomeRF, Bluetooth and Upbanded DECT). Since the data is transmitted and received in different time slots, the same PLL/VCO can be used for modulation and demodulation. Performance is improved by operating in the open loop mode, where the VCO is locked to the desired carrier and the PLL is then shut down during transmission and reception time slots. Particularly in the case of HomeRF, this mode of operation implies that fast lock times are needed, and the drift of the VCO while the PLL is shut down must be acceptably low.

The second order loop filter shown here has a loop bandwidth of 50kHz, giving a lock time of just over 100uS. For low frequency drift when the CMOS switch is open, the VCO has a large 47nF capacitor connected to the control pin. When the switch is closed in order for the PLL to acquire lock, the much smaller size of the required filter capacitance is buffered from the VCO by the LMV921 amplifier.

GSM Power Amplifier Control Loop

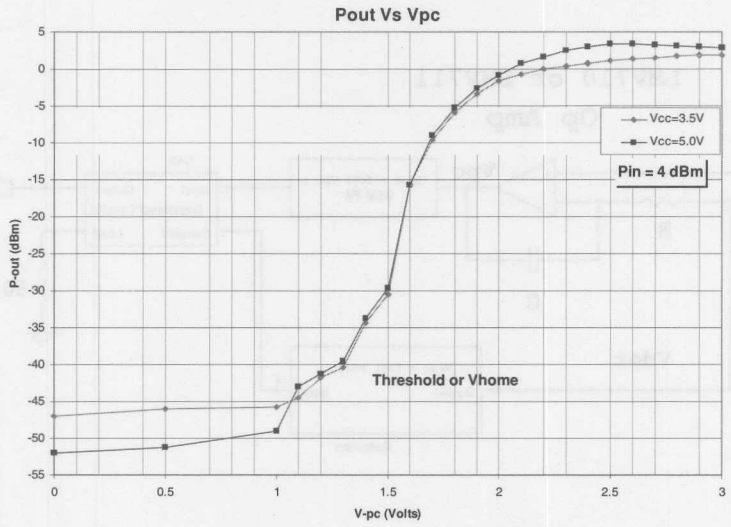


Where low voltage operation at higher speeds is necessary, the LMV710 provides a GBW of 5MHz with a slew rate of 5V/uS. In order to supply the extra speed for stability within a control loop, the LMV710 draws more supply current, 1.2mA, compared to 160uA or less for the LMV921. If overall power consumption is important, the LMV711 in the SOT23-6 package has a shutdown pin which reduces the supply current to 0.2uA in shutdown mode.

In this control loop the Op Amp is used in a differential mode. One input is processing the ramp voltage to set the PA output power level, while the other input is providing a correction voltage for temperature and/or reflected RF power at the antenna caused by temporary mismatching. The amplifier also acts as a filter to prevent high frequency spurs from the controller DAC reaching the PA.

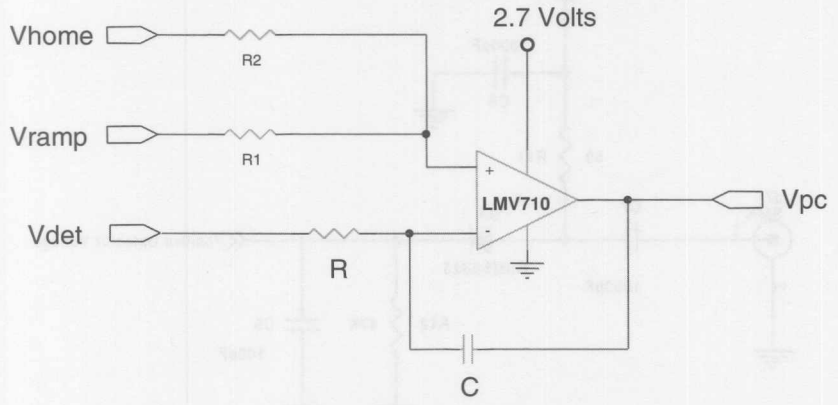
At the output of the PA, a directional coupler is used to feed back the transmitter power level to the controller via an RF diode detector.

Power Output vs V-pc



As the ramp voltage is increased in amplitude, the output power can start out from a very low value with little change until V-pc reaches a threshold level, at which point the power output will go up rapidly with further increases in the V-pc voltage. This threshold value, Vhome, can be preset at the input to the Op-Amp to speed up the turn on time in response to the ramp voltage.

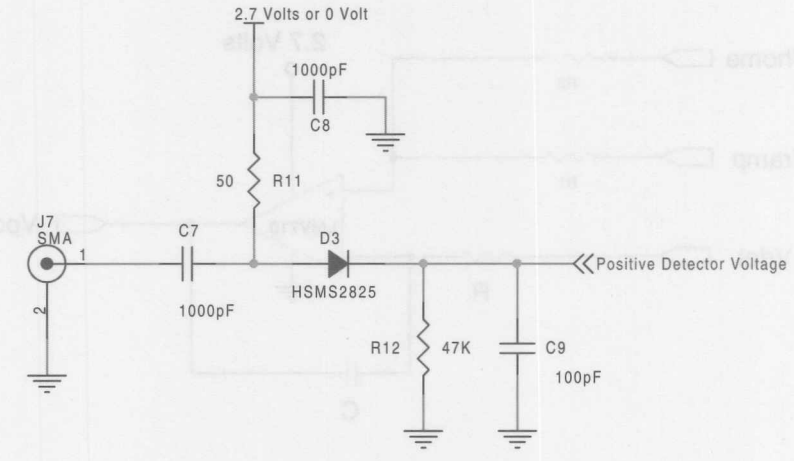
PA Controller with Vhome



Setting Vhome simply requires adding a dc voltage around 1Volt to the non-inverting input of the LMV710.

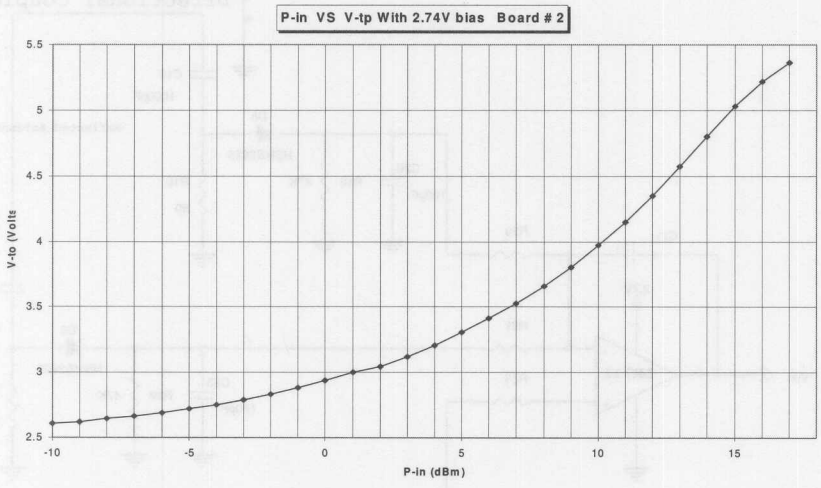
The Vdet correction voltage is obtained from a diode rectification circuit monitoring the rf level from the antenna via a direction coupler. This coupler can take several forms, from a stripline etched in the pcb material, off the shelf SMD components, to wideband resistive dividers or narrow band LC filters.

Positive Detector Rectification



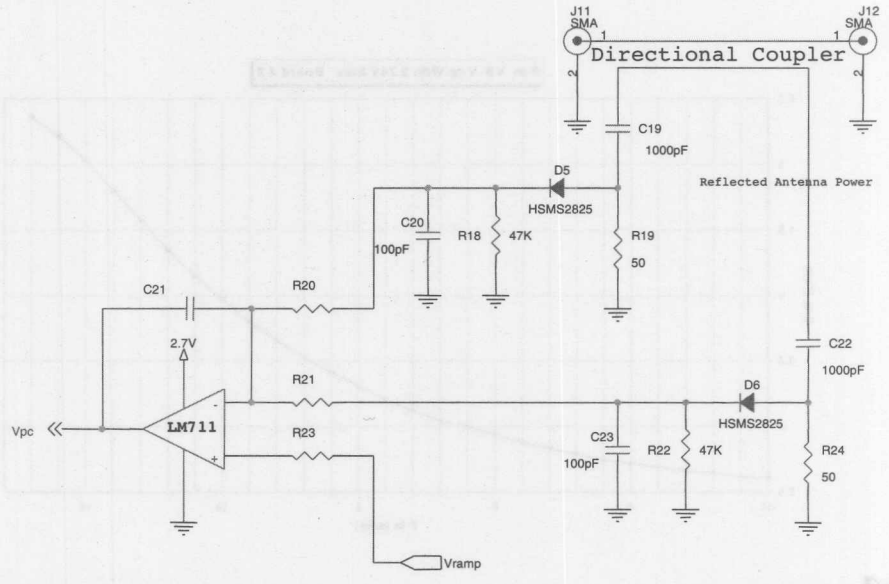
The rectifier circuit shown here uses a diode with the coupler terminating resistor R11 connected to a positive voltage source so that the detected voltage level increases from 2.7V in a positive direction as the power output goes up. If required, with a lower supply voltage for example, the termination resistor R11 can be connected to ground. In either case the diode connection can be reversed to deliver a negative detection voltage.

Detector Voltage vs Power Level



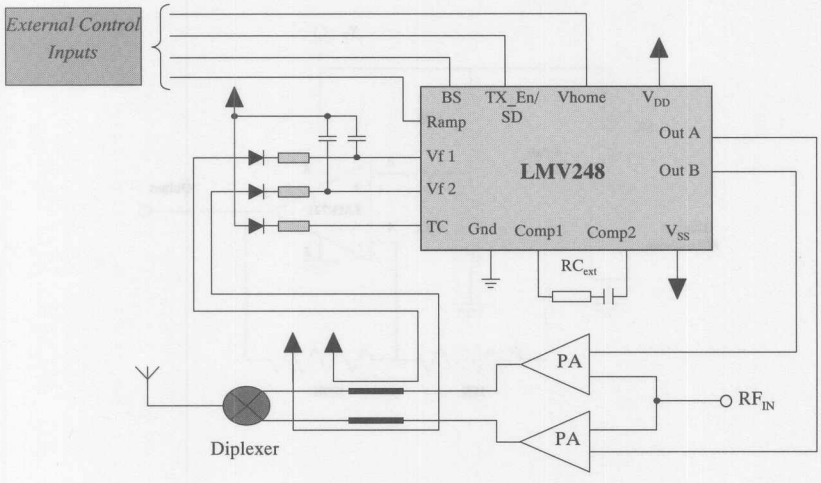
This graphic shows the response of a typical diode circuit with a 2.7Volt bias. If a lower supply voltage means the terminating resistor is connected to ground, then the whole curve becomes level shifted down with only a small change in the overall shape.

Forward & Reflected Power



This more complete schematic, using the LM711 includes a second rectifier diode D6. This is designed to protect the PA when the antenna is inadvertently load mismatched.

LMV248 Dual Band Controller

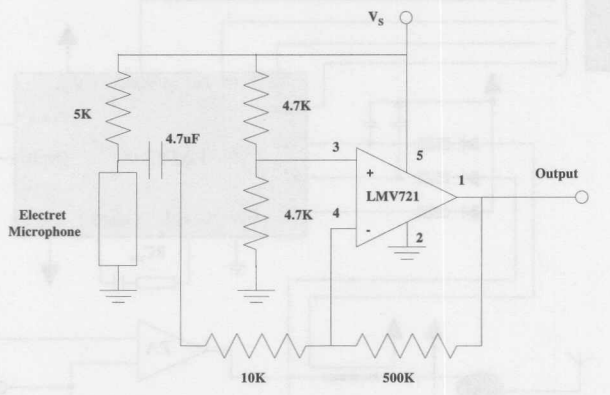


Versatile as they are, just so much can be done with just an Op-Amp. The LM248 is the first in a family of dedicated controllers and, as such, is able to combine many of the desired features into a single I/C.

A band select pin (BS) enables either of the two outputs for GSM or PCN. The ramp and Vhome voltages are applied at two other pins and, as before, a directional coupler is used to feed back the transmitted or reflected power levels to the I/C. There is an additional diode connected in close proximity to the detector diodes in order to provide temperature compensation.

The I/C is able to support GaAs FET, GaAs HBT and bipolar RF power amplifiers with two pins provided for loop compensation. To save power when not transmitting, both output drivers are set to the lowest voltage level. When transmit is enabled, the unused driver is kept at the low voltage state.

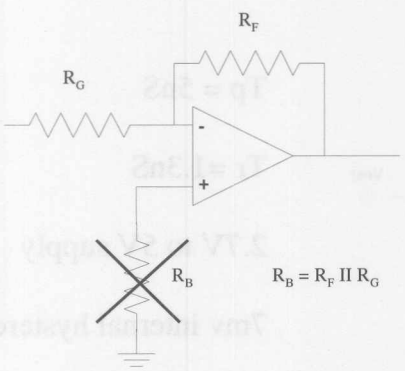
LMV721 Microphone Preamplifier



For yet more speed, where Rail to Rail inputs are not required, the single supply LMV721 single Op-Amp and the LMV722 Dual Op-Amp are available. These amplifiers are able to deliver a 10MHz GBW while drawing barely 1mA of supply current. Along with a noise voltage of less than 10nV$\sqrt{}$Hz, this wide bandwidth makes the Op-Amp a good candidate for high gain audio applications.

The microphone preamplifier shown here has a closed loop gain of 34dB (50) which means that the closed loop bandwidth will be around 200kHz. This is a factor of 10 higher than the 20Hz to 20KHz audio bandwidth, which will help keep the distortion low. In this inverting gain application the the non inverting input is biased to half the supply voltage, but with some microphone elements a non inverting configuration can be used with the inverting input grounded. This is possible because the LMV721, in common with most single supply amplifiers, has a common mode input that includes ground.

LMV751



4.5 MHz GBW

Vos 0.05mV

2.7V to 5V operation

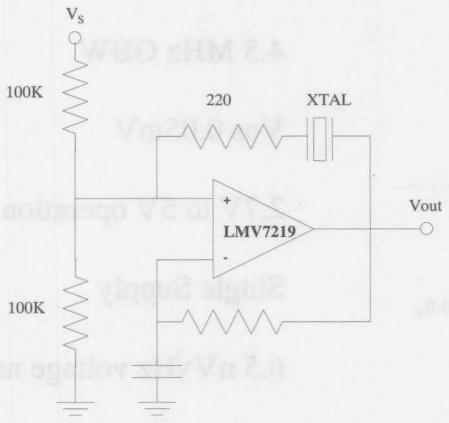
Single Supply

6.5 nV√Hz voltage noise

Another single supply Op-Amp is the LMV751. The GBW is midway between the general purpose Op-Amps (1MHz) and the high speed LMV721/2 series, and it has been optimised for lower noise, 6.5 nV√Hz, and the ability to drive capacitive loads as high as 1000pF. The LM751 is fabricated on a CMOS process with a bipolar module to provide this drive capability.

While the LMV751 has a low input referred noise voltage, in a given application the external bias and gain setting resistors can be significant contributors to the overall noise performance. It is common practice to match the inverting and non-inverting resistive networks to an Op-Amp. This stems from the bipolar days when input offset currents could contribute to the output offset voltage if these resistances were not matched. The input bias currents of CMOS Op-Amps is very low compared to a bipolar input stage, and the input offset current is correspondingly low, in the case of the LMV751 it is only 0.2pA. This mean that matching the input resistors is not as important and can lead to the complete removal of the non inverting resistor in a single supply application. A further benefit is that the resistor's contribution to output noise voltage is also eliminated.

LMV7219 High Speed Comparator



Tp = 5nS

Tr =1.3nS

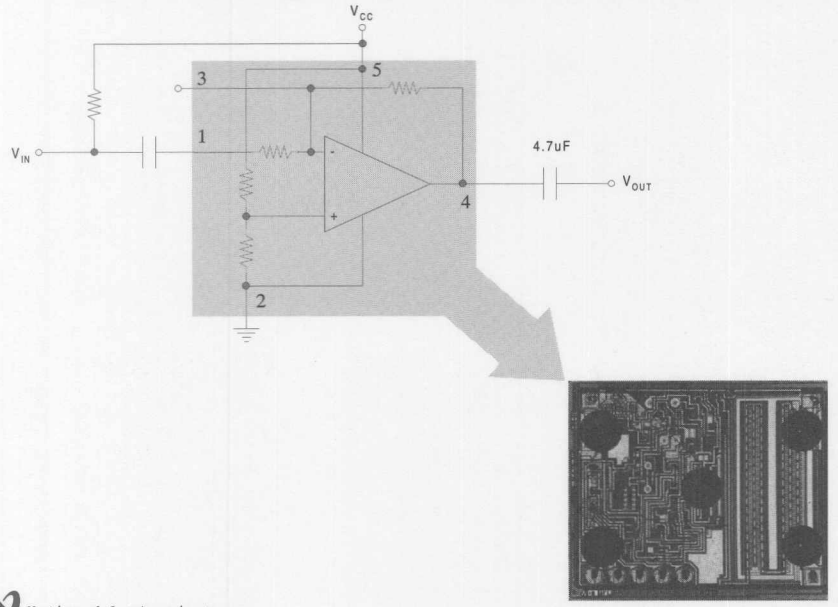
2.7V to 5V supply

7mv internal hysteresis

There is always a temptation to use an available Operational Amplifier as a comparator. While this is more true of quad Op-Amps than the singles (or even the duals) we have been describing, the speed of these devices suggests that they might make reasonably fast comparators operating at the same low supply voltages. This should be approached with caution. For example the bipolar output stage of the LMV751 with a light load will allow the the PNP to saturate, diverting the output current to the previous stage instead of into the load. This causes the supply current to increase to 20-30mA, which could be disastrous. Even when this is not the case, since the Op-Amp is usually compensated for stable operation at unity closed loop gain, the comparator speed will be a lot less than an uncompensated version would be.

A better solution is to look for a comparator able to work on low supply voltages. The LMV7219 is available in SC70-5 or SOT23-5 packages and will work on supply voltages as low as 2.7V. The propagation delay is only 7nS and 7mV of internal hysteresis is built into the switching threshold to avoid oscillations caused by noise on the input when it is close to the switch point.

LMV Integrated Fixed Gain Family



Last, but not least, is the LMV1xx fixed gain family.

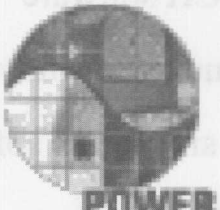
Because of their intended general purpose use, Op-Amps are surrounded by external components that define the particular function. With surface mount components, these external parts occupy less pcb space than the I/C. Now, with the much smaller packages described earlier, this is no longer the case. Therefore, in large volume applications for a fixed function, it makes sense to bring some of these external components inside the I/C package. Although only very small capacitors can be integrated (< 30pF), resistors up to several hundred kilohms in value are easily included on the I/C die.

Our LMV family includes a number of Op-Amps with outputs biassed to half supply, and inverting gains from -1 to -10.

	DC Gain
LMV101	-1
LMV102	-2
LMV105	-5
LMV110	-10

Another part is the LMV111, which is similar to the LMV321, but has the output biassed to Vcc/2

Design Your Power Supply On Line



POWER.NATIONAL.COM

Presentation Outline

- Background on POWER.NATIONAL.COM
- Overview of WEBENCH software
- WebSIM electrical simulation software
- WebTHERM thermal simulation software
- Build It prototype procurement

National Semiconductor has been a leader in power management products since its inception. National has also been a leader on the web since 1994. Combining both of these attributes, National has taken its 30 years of power supply knowledge and put it on the web at POWER.NATIONAL.COM.

National is a leader in power management:

Invented LDO regulator

Simple Switchers product line a pioneer in the switch mode regulator field

Extensive resources and history in power arena

National's website was created in 1994

Web firsts for semiconductor industry:

-Parametric search, On line ordering of parts, On line electrical and thermal simulation, On line custom prototype boards

In this seminar we will discuss POWER.NATIONAL.COM and show how to use the WEBENCH, WebSIM and WebTHERM software tools.

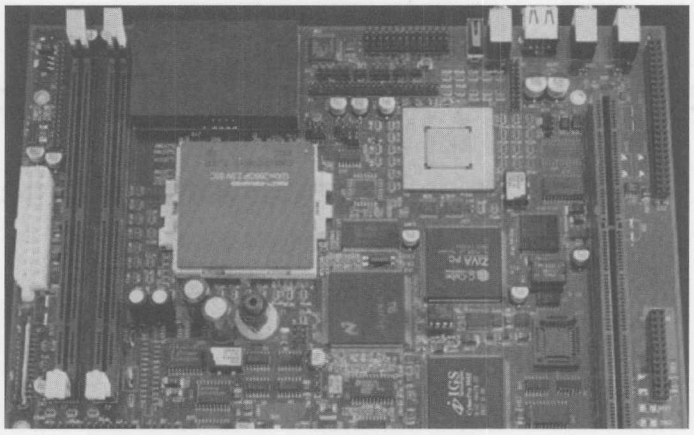
The Goal of POWER.NATIONAL.COM

Create a highly productive design experience

that saves our customers time

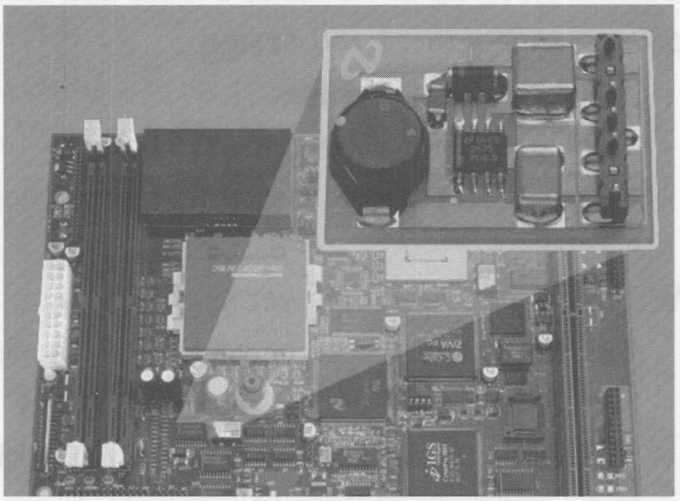
Before we created our web site, we defined our goal

Customers' Design Expertise and Time Goes Into the Main Board



Customers put their time and effort into the main board, and typically do not want to spend a lot of time designing a proprietary power supply circuit.

Objective: Get to This as Quickly as Possible



At POWER.NATIONAL.COM, National can provide the customer with a plug in power supply which is customized to the specifications of the customers design.

We asked our customers to tell us what they wanted and it was a tall order.

Our Customer's Vision

"I want to describe my requirements, simulate my design, and select vendors in the same morning."

…... "Oh, and never load any software or administer any servers"

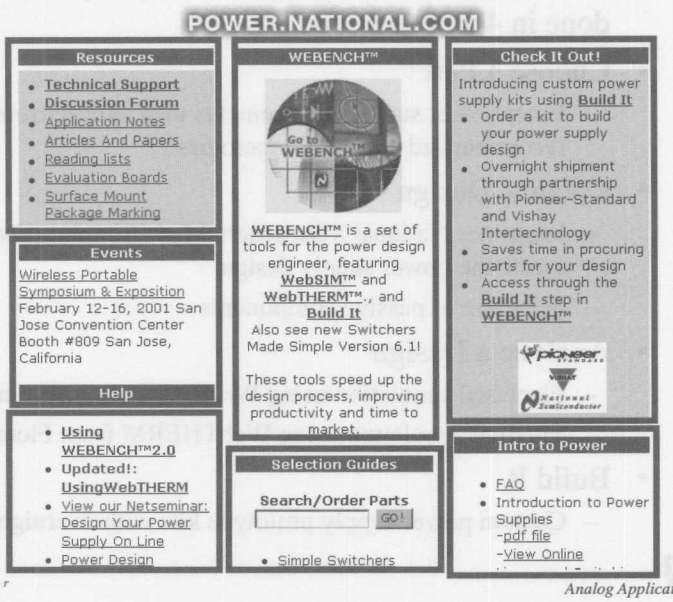
POWER.NATIONAL.COM Features

- Collection of all of National's tools and information for power management and design
 - Interactive selection guides
 - Application notes, datasheets and articles
 - Help, technical support, discussion forum, introductory materials
- WEBENCH: On line power supply design
 - Selection and calculation of passive components
 - Real time electrical simulation using WebSIM
 - Board level thermal simulation using WebTHERM
 - Order prototypes on line with overnight shipment

POWER.NATIONAL.COM features all of Nationals information in one place and also WEBENCH, the on line power supply design environment.

POWER.NATIONAL.COM
"For Engineers, By Engineers"

All the information you need in one place

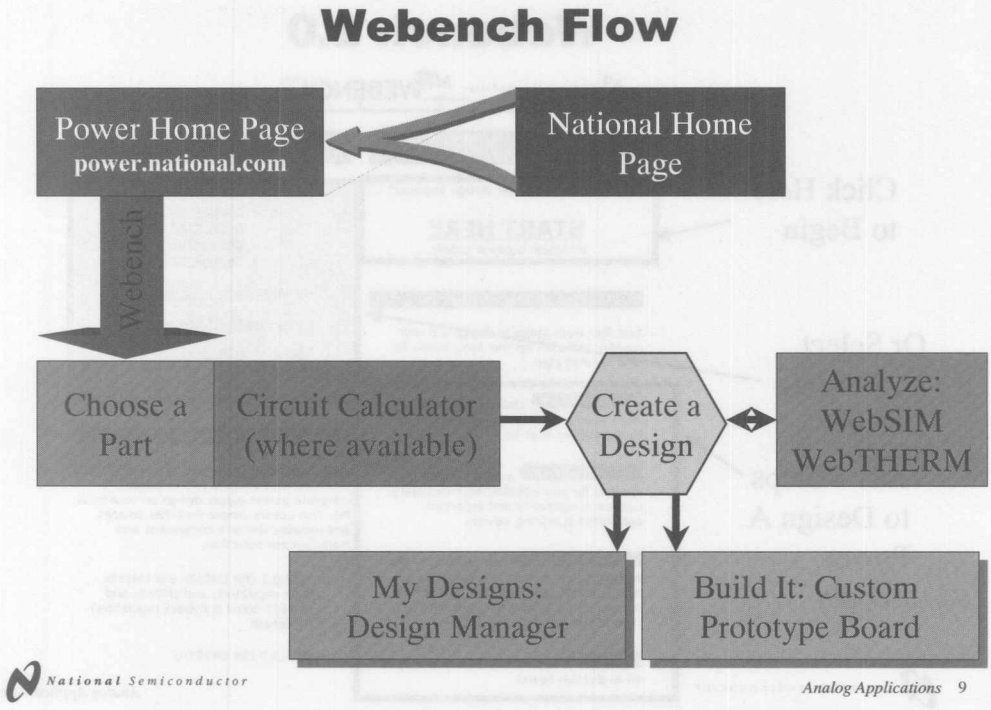


The front page of POWER.NATIONAL.COM is provides a wealth of information for power supply designers. This includes application notes, articles and papers, a reading list, evaluation boards and a discussion forum. There is also a link to our email technical support to get questions answered by our experts. There is on line help for using WEBENCH, system diagrams for power supply applications, selection guides which enable the user to choose a National power part based on product family, and the latest news from the industry and National. There is also an introductory section with helpful articles to brush up on power supply design fundamentals, and last, but not least, is a link to WEBENCH. WEBENCH is a set of on line tools which allow a user to design, simulate and procure a power supply on line. This can shorten the design cycle dramatically.

Webench Features

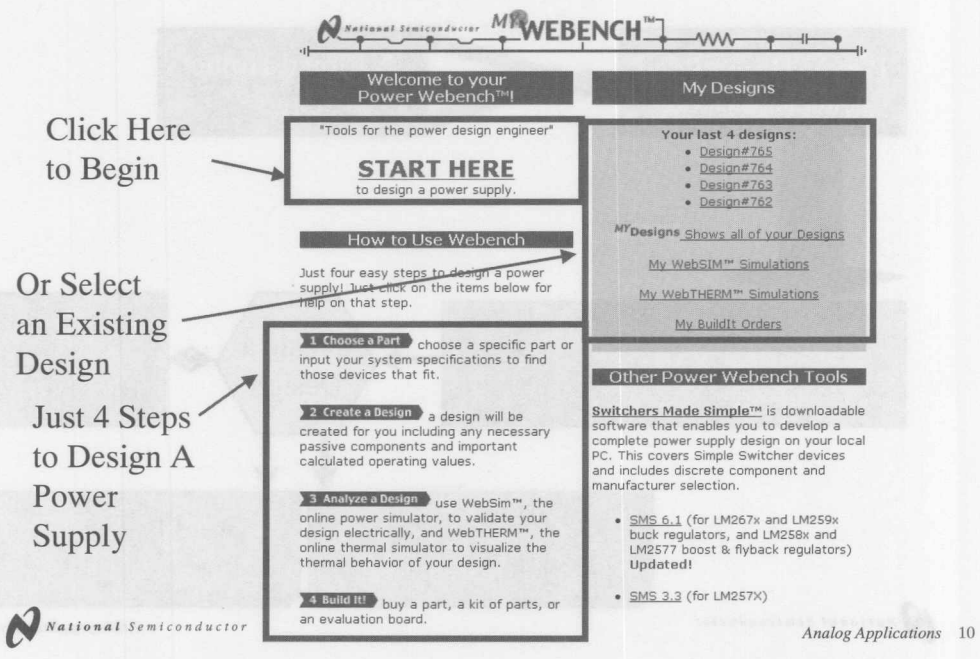
- Webench is an end to end solution for power supply design done in 4 simple steps:
- Choose a Part
 - Enter power supply requirements then choose from a list of recommended parts and topologies
- Create a Design
 - Integrates National's Switchers Made Simple software to automatically create the power supply design
 - Selection of passive components
- Analyze a Design
 - Electrical simulation using WebSIM from Transim
 - Thermal simulation using WebTHERM from Flomerics
- Build It
 - Custom power supply prototype kits with overnight shipment

Webench is an end to end solution for power supply design.



From the Webench start page, the user goes to choose a part, which provides the list of possible devices. When one device is chosen, the design information is passed through a Circuit Calculator (if it is available for that device), and a Design is developed. This Design can then be electrically and thermally simulated, and a custom prototype board can be obtained for the design.

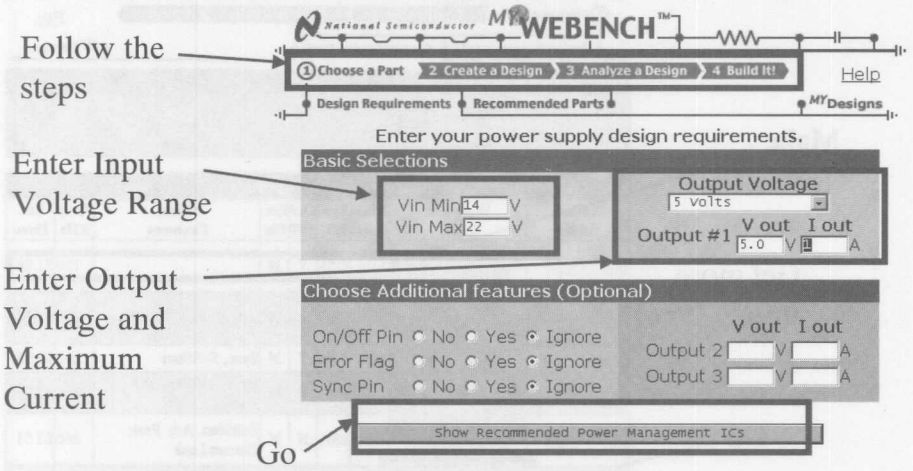
Webench 2.0



The Power WEBENCH page, accessed from POWER.NATIONAL.COM, provides you with the on line tools to design a power supply faster than ever before. Click on the START HERE to design a power supply link to begin a new design. Or, if you already have WEBENCH designs, you can access them by clicking on the links from your last 4 designs in the upper right side of this page.

You can also download Switchers Made Simple 6.1 which is the latest revision of the offline software. This software aids in the design of simple switcher based supplies and provides component selection, but no simulation.

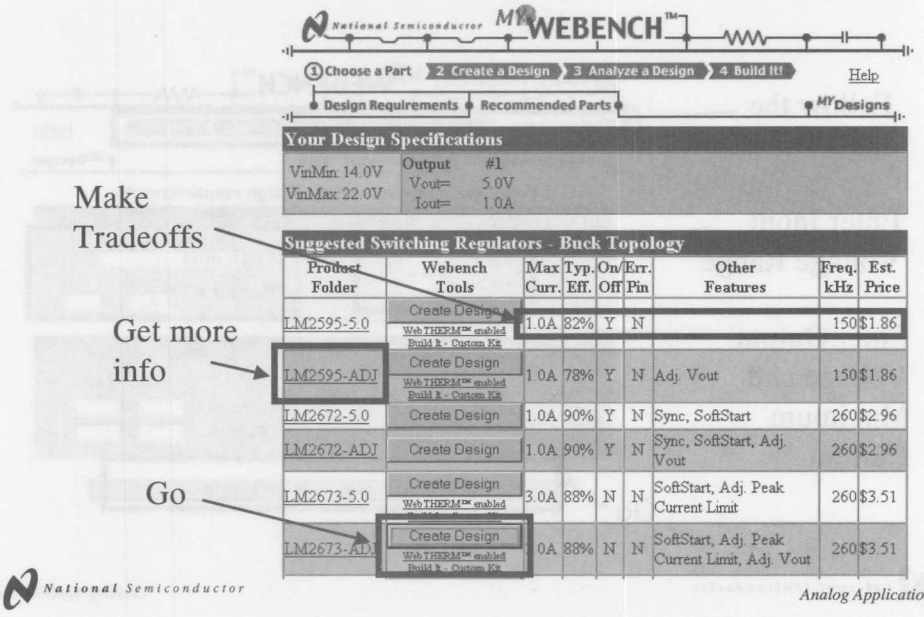
Enter Your Requirements



On the top of each screen in WEBENCH is a set of 4 buttons which tell the user which step the design process is in. These steps are Choose a Part, Create a Design, Analyze a Design and Build It.

The first step is to enter the power supply design requirements in the Choose a Part screen. Simply enter the range for the input voltage (Vin), the desired output voltage and the output current. After entering the design specifications, press the button at the bottom of the screen to Show Recommended Power Management ICs.

Select a part

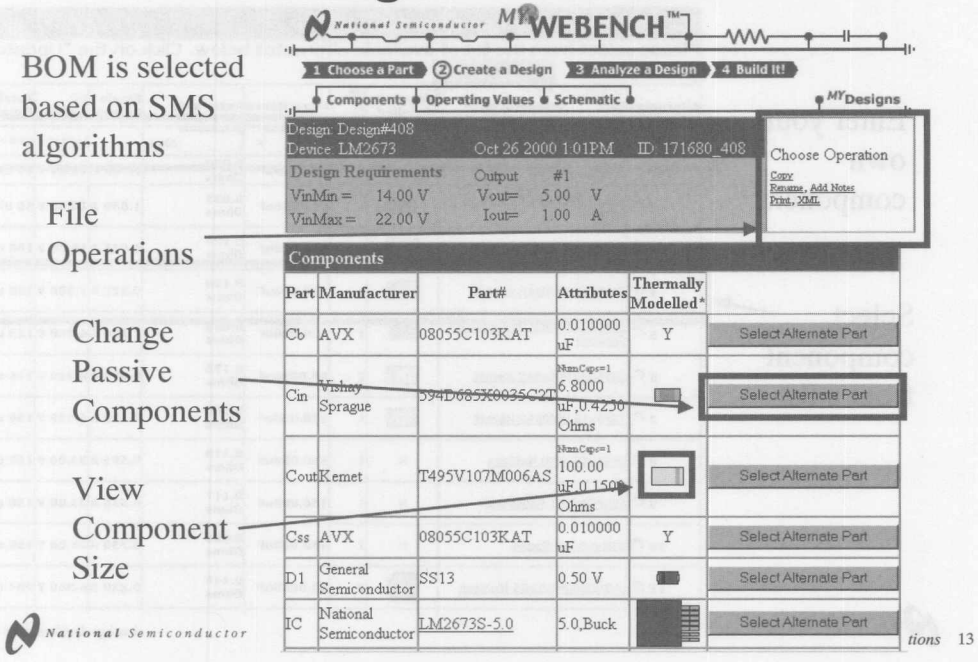


On the Recommended Parts page, a list of devices is presented which includes Power Management products which address your power supply requirements. A number of useful parameters are displayed including efficiency and price which help you select the best part to meet your needs. If you desire more information about a device you can go to the device Product Folder, using the link in the left column of the display

Text indicators below the Create Design buttons show whether the device is WebTHERM enabled meaning it can be simulated thermally. If the text indicator says Build It – Custom Kit, a custom prototype kit is available in the Build It step.

After you decide on the best voltage regulator, click on the Create Design button to have WEBENCH create your design in your personal workspace.

Design - View BOM

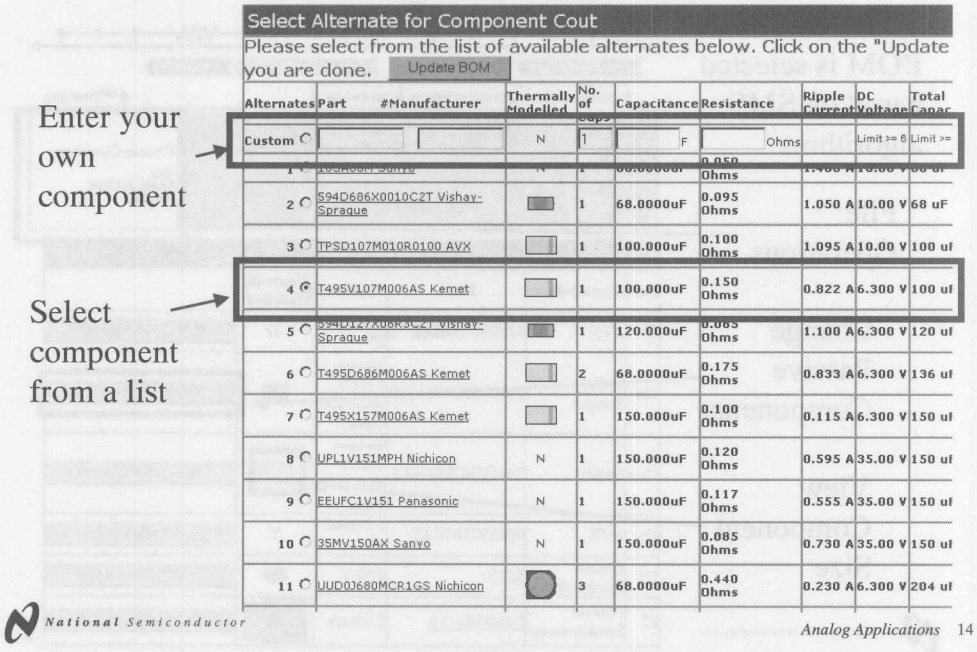


This is the View Components screen. It summarizes the design thus far, including the power supply requirements and the IC selected. In addition, the external components needed for the total solution are listed, with manufacturer, part number, and key values. A top view scaled drawing of each thermally modeled part is also shown. Parts which are not required by WebTHERM are indicated by a Y in the thermally modeled column. The component selection, as well as the operating value calculations, are done using the same algorithms as are used in Switchers Made Simple.

From here the user can view the operating values, simulate the design using WebSIM, work with the design file name & information, or select alternate component values for the design. The components are determined by the Circuit Calculator routine, and are recommended for good operation of the circuit. For devices not supported by the Circuit Calculator, default components and values are provided (matching those shown as defaults in WebSIM).

Alternate components also come as a result of the Circuit Calculator. As an example, we will look at the list of alternate output capacitors.

Select Alternate Part

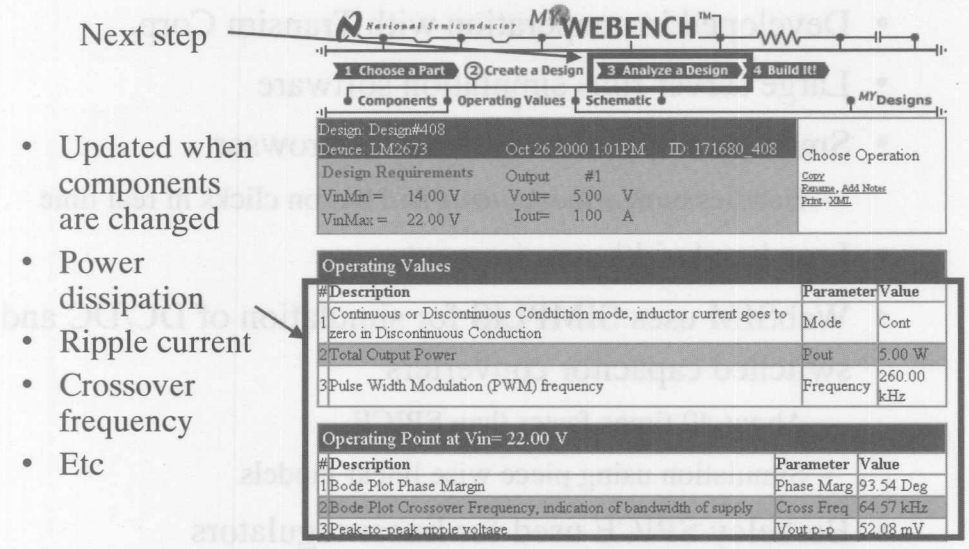


For this design, the suggested alternative capacitors are listed. All are appropriate for this power supply design. However, if another capacitor was desired that is not listed, it could be entered as "custom" (Be sure to click on the custom button if you want to enter custom values). Notice the ability to select multiple capacitors in parallel to reduce the equivalent series resistance.

Design – Operating Values

Next step

- Updated when components are changed
- Power dissipation
- Ripple current
- Crossover frequency
- Etc



The Operating Values page gives the result of calculations for the power supply design. These calculations were used in the selection of the design components, and are reported here to give an estimate of the circuit performance. In this example, the operating values that are provided include the following:

Bode Plot Phase Margin, Bode Plot Crossover Frequency

Steady State Efficiency, Continuous or Discontinuous Conduction mode

Total Output Power

IC Power Dissipation, Diode Power Dissipation

Input Capacitor Power Dissipation, Inductor Power Dissipation

Average input current, Input Capacitor RMS ripple current

IC Junction Temperature, IC Junction to Ambient Thermal Resistance

Vout p-p, Inductor ripple current, Output Capacitor RMS ripple current

Peak Current in IC for Steady State Operating Point, IC Maximum rated peak current

Steady State PWM Duty Cycle, Pulse Width Modulation (PWM) frequency

Clicking the "Components" tab will take you back to the previous page showing the components used in the design. If you change component values, the Operating Values will be updated.

For further investigation of the design, you can analyze it using the online WebSIM and WebTHERM simulation tools.

What's Behind WebSIM?

- Developed in cooperation with Transim Corp.
- Large server runs simulation software
- Small java applet runs on user's browser
 - Handles mouse movements and button clicks in real time
- Low bandwidth requirement
- WebSIM uses SIMPLIS for simulation of DC/DC and switched capacitor converters
 - About 40 times faster than SPICE
 - Simulation using piece wise linear models
- Berkeley SPICE used for linear regulators

National Semiconductor

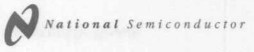
Analog Applications 16

WebSIM is a product of the Transim Technology Corp., formerly known as Power Design Tools. Because WebSIM resides on a fast, high-powered server, the user does not need to have any special software loaded on his/her PC to be able to use it. The models and simulation engine software on the server are always up to date, so the user gets the most current information.

Only short data files are transferred between the user and the server across the Internet, so to set up and run a simulation is very fast. The simulations are also quick because the switching regulator and switched-capacitor models are in SIMPLIS, a Transim-proprietary modeling and simulation tool that is much faster than SPICE for switching circuits.

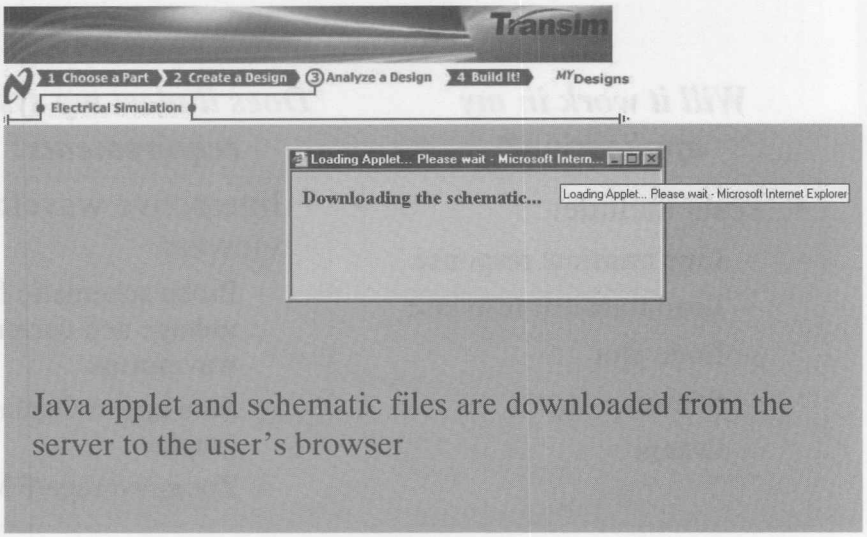
Design Engineers Can Investigate Their Questions

Will it work in my application?	*Does it meet my system requirements?*
• Tests include: – Line transient response – Load transient response – Bode plot – Startup – Others	• Interactive waveform viewer: – Probe schematic for voltage and current waveforms – Java applet displays graphs – Zoom/average/RMS



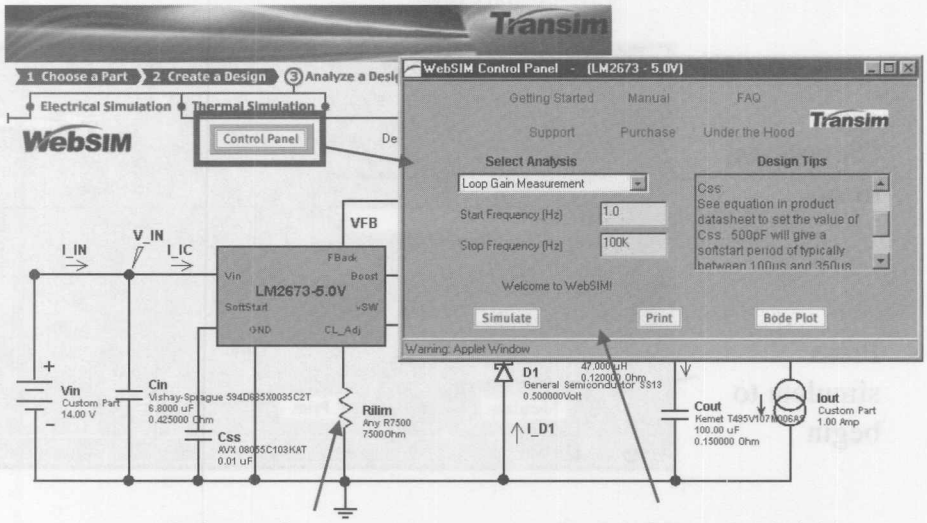
WebSIM allows the users (our customers and field staff) to investigate questions related to their specific circuit. To answer questions about whether the circuit will work in the customer's application, components can be adjusted in infinite combinations , and any of several tests can be run. When the schematic is probed, the waveforms are presented in an interactive Java-based viewer that allows measurements using moveable cursors, plus shows measurements based on the entire waveform.

WebSIM Loading



When a device is selected to work on in WebSIM, the first thing you will see is a large gray rectangle (where the schematic will go) and a small status box. The status box explains, in the small white type, that the system is downloading the Java applet that provides the interface to the schematic. It may take over a minute, perhaps a up to 3 minutes on a slow modem, to download the schematic. Download time also depends on the virus checker being used and the type of virus checking being done (programs or programs+data). Downloading is much faster after the first time.

WebSIM Schematic

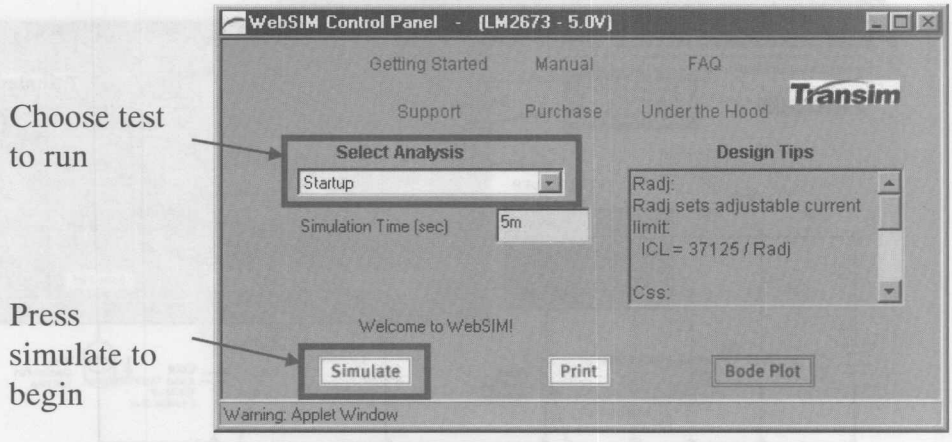


Schematic – use mouse to change/view

Control Panel – initiate simulations

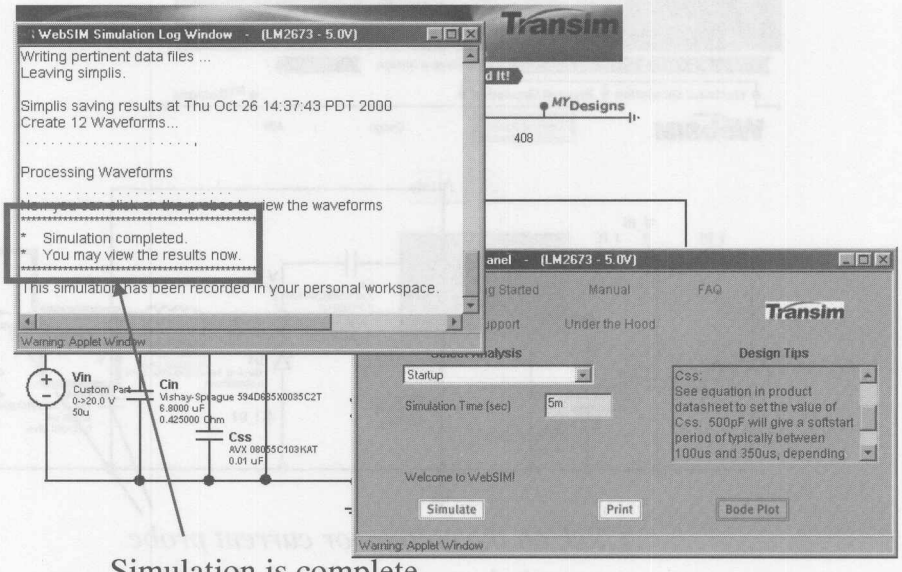
Simulations are set up using the WebSIM control panel. If the control panel is closed, the user can reactivate it by pressing on the Control Panel button in the schematic. The user can view component details by clicking on the corresponding symbol on the schematic. This brings up a window which allows the user to choose an alternate part if desired, or enter a custom value for that component. The voltage and current probes are not accessible until a simulation has been run.

Control Panel



Once WebSIM is downloaded, the Control Panel appears. It is from the Control Panel that the various tests are customized and selected. There is also additional information for the user, from design tips about this specific schematic to information about how WebSIM works.

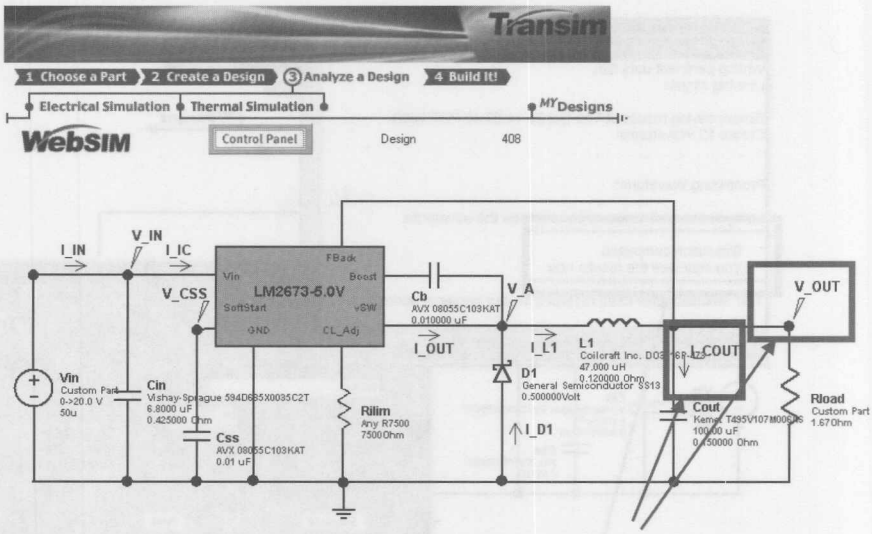
Simulate the Circuit



Simulation is complete

Once the schematic values are adjusted as needed, we can run a test; for example, Startup. We accept the default simulation time of 5ms, and hit the Simulate button to start the simulation. A new box appears, showing cryptic text and numbers. As it scrolls down, it eventually gets to the text shown in the window above. If this text has not appeared, the simulation is not yet done! The actual simulation time is usually a few seconds or less; it may take a minute or so to send the data back & forth, depending on modem and connection speed.

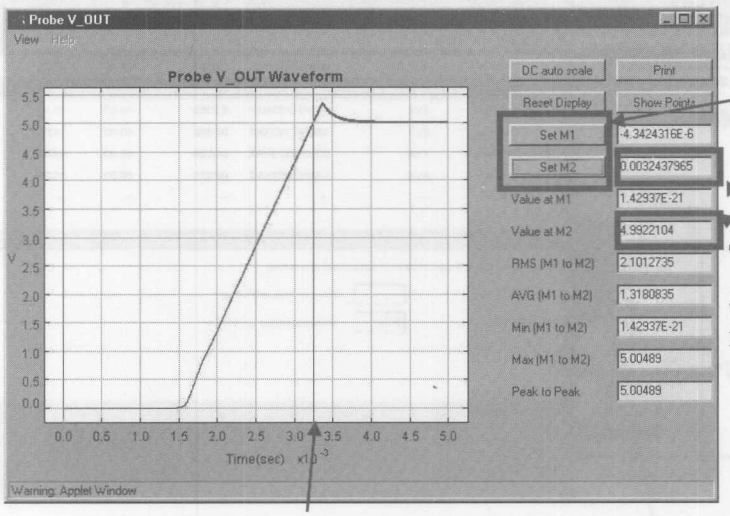
View Waveforms



Click on the voltage or current probe symbols to view the waveforms

For the Startup test, as well as the transient and steady-state responses, two type of probes are available. The current probe allows the user to view the current through a component, and the voltage probe allows a look at the voltage with respect to ground.

Vout Waveform



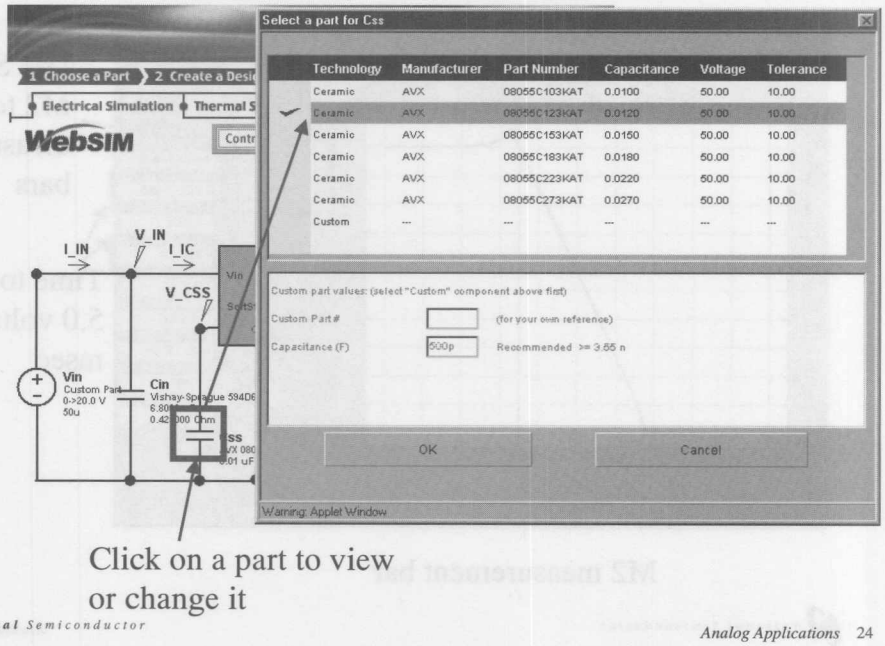
Use Set M1, M2 to create measurement bars

Time to achieve 5.0 volts = 3.2 msec

M2 measurement bar

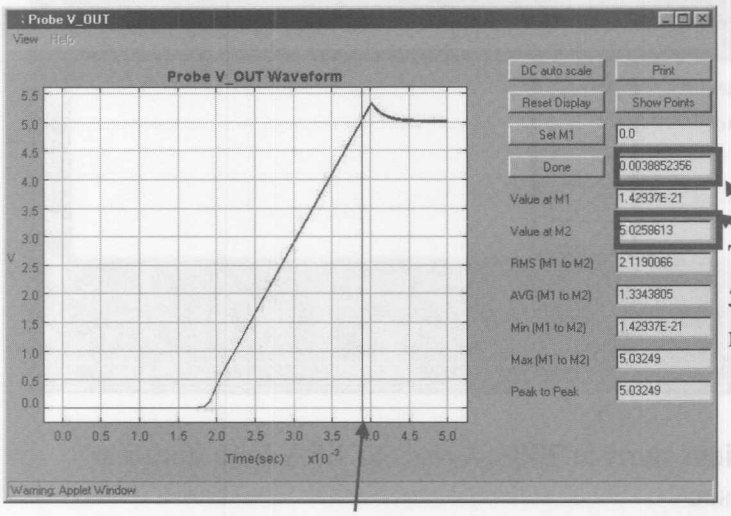
In this case, we see that with an input voltage step of 0V to 20V in 50us, the output rises to the target value of 5V in 3.2milliseconds, with a bit of overshoot. (This is very close to what is seen on the bench.) The rise time can be controlled with the soft start capacitor Css.

Changing Components



We change the soft start capacitor from 10 nF to 12 nF and run another simulation

Vout Waveform After Css Change

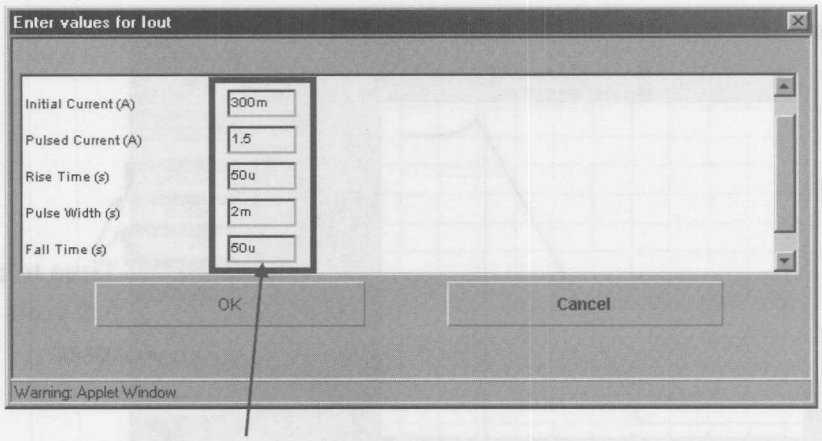


Time to achieve 5.0 volts = 3.9 msec

M2 measurement bar

Then we see that the time to reach 5 volts has increased from 3.2 milliseconds to 3.9 milliseconds

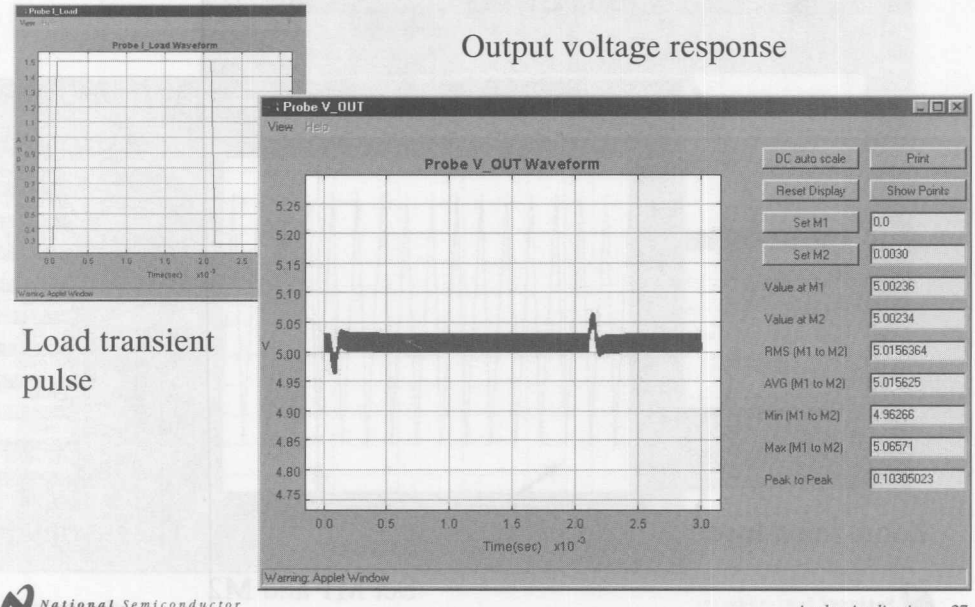
Load Transient Test



Transient starts at 300mA,rises to 1.5A for a duration of 2msec

To run the Load Transient Response test, first click on the Iout symbol in the schematic to check the load transient settings and adjust them if necessary. The settings include the initial current level, the maximum current level, rise time of the pulse, the duration (pulse width), and the fall time. Here we have adjusted the load transient to step from 300mA to 1.5A, with a duration of 2ms. The rise and fall times are unchanged at 50us. In the Control Panel, the overall simulation time is set to 3ms.

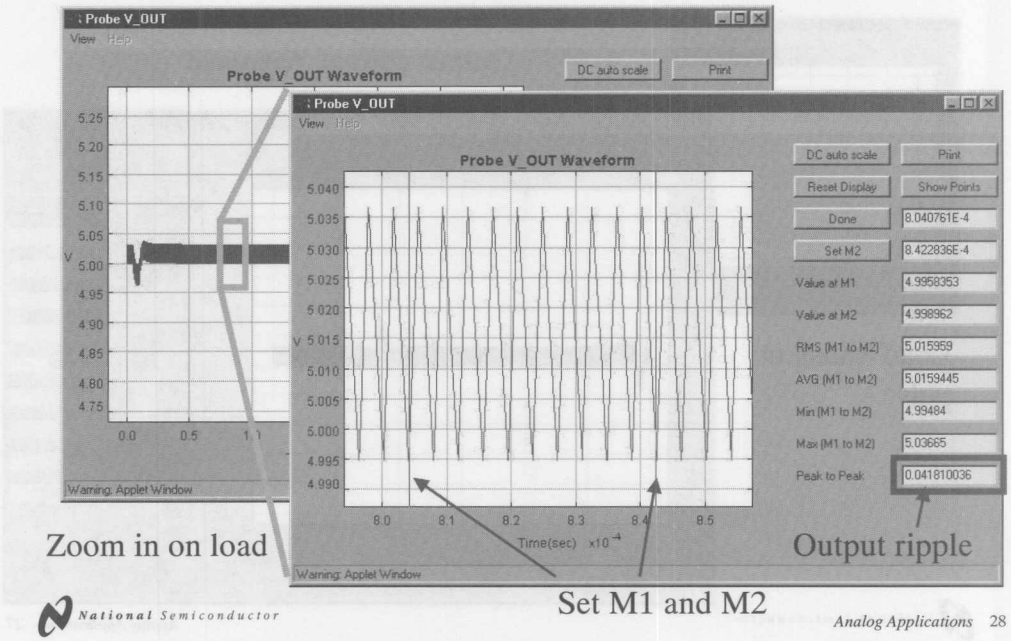
Vout for Load Transient



National Semiconductor

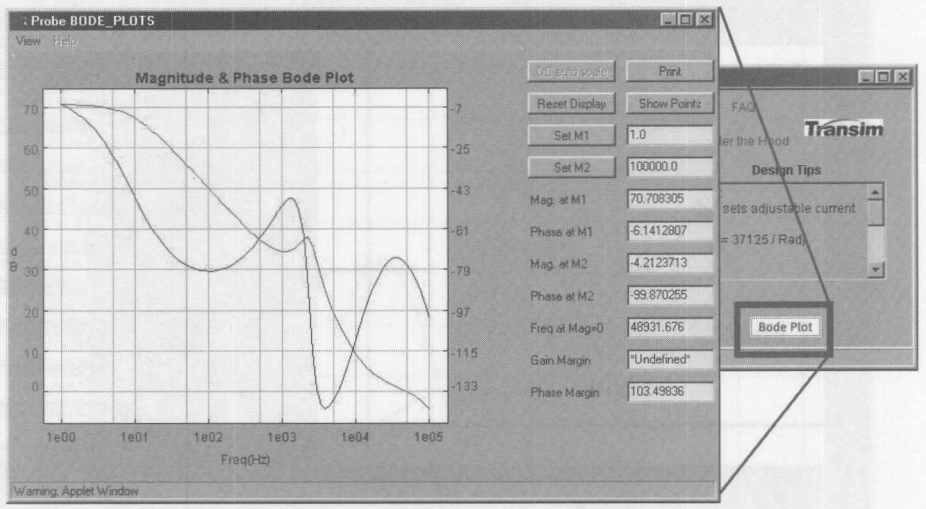
After we run the test, and get the message that the simulation completed; you may view the results now, we click on the output voltage probe, and see the perturbations in the waveform due to the load transient. It is reasonably well-damped, with just one cycle of ringing.

Output Ripple Voltage



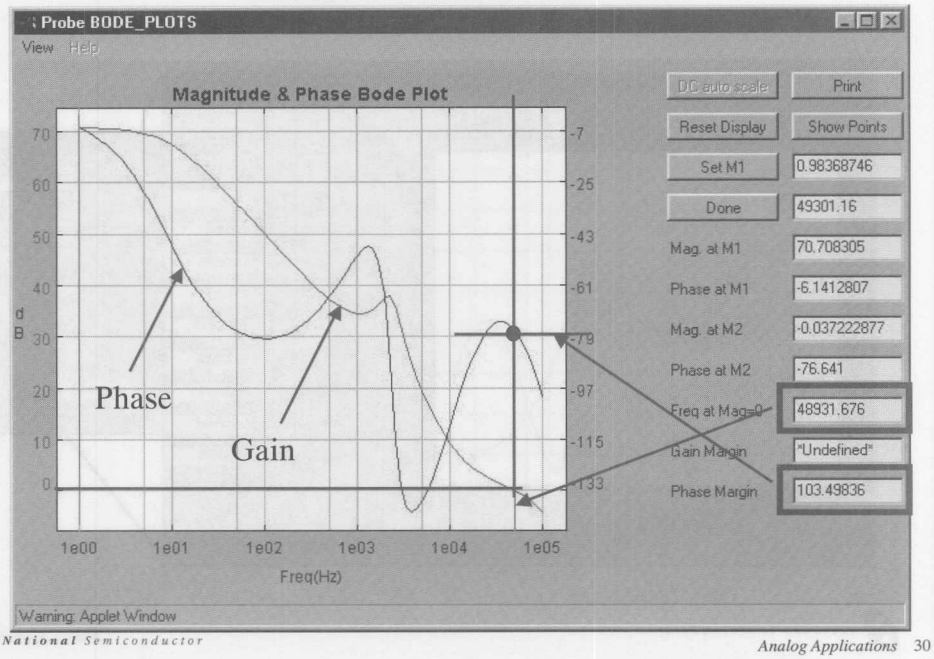
We can zoom in on a section of the waveform, and see the output voltage ripple due to the switching action of the regulator. In the zoomed-in view, we can take advantage of the built-in calculator to measure the peak-to-peak output voltage ripple at full load, a little less than 42 mV.

Bode Plot



A test that is time-consuming to set up on the bench is the frequency response but with WebSIM it is very easy! After confirming that the start and stop frequencies are OK (they usually are), click the Simulate button. When the calculations are done, a click on the Bode Plot button brings up the frequency response plot for this circuit. The gain (in red) and phase (in blue) are displayed together.

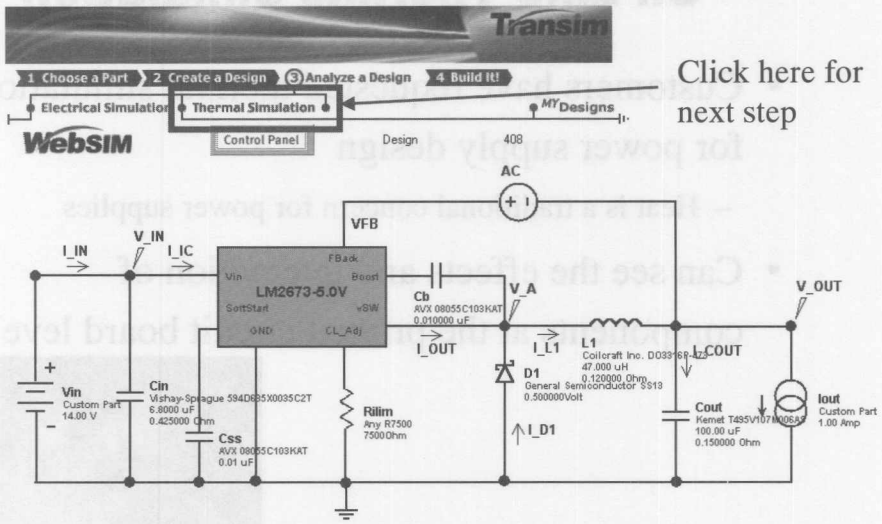
Bode Plot Details



The built-in calculator identifies the unity-gain frequency to be 48.9kHz, with a phase margin of 103 degrees. This is a good phase margin, allowing for variations in component value without getting near an unstable condition.

Note for those who are rusty at frequency response evaluations: A regulator, or any feedback controlled system, is unstable if its total phase shift around the control loop is 360 degrees when the gain is 0dB (unity). The use of negative feedback contributes 180 degrees, and the amplifiers and other circuitry used in the power stage of a regulator contribute additional phase shift. The difference between the 360 degrees and the actual total phase shift at unity gain is the phase margin. If the total phase shift is 360 degrees, there is no phase margin. In this case, we have a total phase shift of 180 + 77= 257 degrees, for 103 degrees of phase margin. If the phase margin is greater than about 90 degrees, the regulator is overdamped - very little ringing when presented with a transient. If the phase margin was less than about 20 degrees, the regulator would be in danger of having no phase margin if a key component aged or otherwise changed its value.

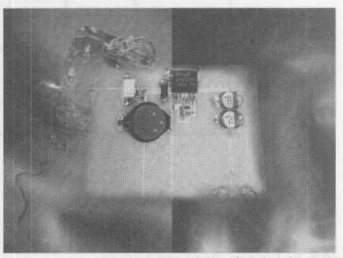
Electrical Simulation Done



The WebSIM simulation process allows the user to adjust components to achieve the desired electrical outputs. When the user is done with electrical simulation, click on the Thermal Simulation tab to begin using WebTHERM.

WebTHERM
On Line Thermal Simulation

- Customers have requested thermal simulation for power supply design
 - Heat is a traditional concern for power supplies
- Can see the effects and interaction of components at the printed circuit board level



National Semiconductor

WebTHERM was developed as a result of customer demand. It is a unique tool which allows the user to see interactions between the physical and electrical elements of the circuit.

Flomerics

- Clear market leader in thermal simulation for electronics
- $14M in sales in 1999
- Founded in 1988 by experts in computational fluid dynamics (CFD)
- Introduced FLOTHERM in 1989
 - First CFD thermal simulation software for electronics industry
- Released FLOPACK in 1998
 - First web based tool for generating thermal simulation models

National partnered with Flomerics to develop WebTHERM. Flomerics is the market leader for thermal simulation for electronics with it's flagship simulation tool, Flotherm, based on CFD.

WebTHERM Features

- Generates color thermal images of PC board to visualize thermal effects
- Shows temperatures of each component
- Heat sinks
- User can adjust environmental variables to improve heat dissipation
- Saves time and avoids costly mistakes in power supply design
 - Bench setup for temperature testing is time consuming!

National Semiconductor

Analog Applications 34

WebTHERM generates a color plot of the temperatures across the PC board. This is a powerful tool for locating hot spots and problem areas. In addition, the maximum temperatures of each component are listed in a table. The user can adjust environmental variables to improve heat dissipation on a virtual circuit, thereby saving time and avoiding problems later in the design cycle.

WebTHERM Architecture

- Uses Flomerics Smart Part models for the IC
- Uses lumped cuboid models for passive components
 - Will be converting diode to Smart Part
- Board modeled as a separate part, with traces modeled explicitly
- 3D conduction
- Radiation
- Convection modeled through correlations

National Semiconductor

Analog Applications 35

WebTHERM uses two types of models for electrical simulation. For the IC (and soon the diode), WebTHERM uses Flomerics Smart Part models which are highly detailed and based on the internal construction of the parts. For other passive components, lumped cuboid models are used which assume the power is distributed evenly across the cubic volume of the component. Since the passive parts do not typically generate a lot of heat, this type of model is appropriate. The board traces are modeled explicitly to accurately portray how heat is transferred over the copper.

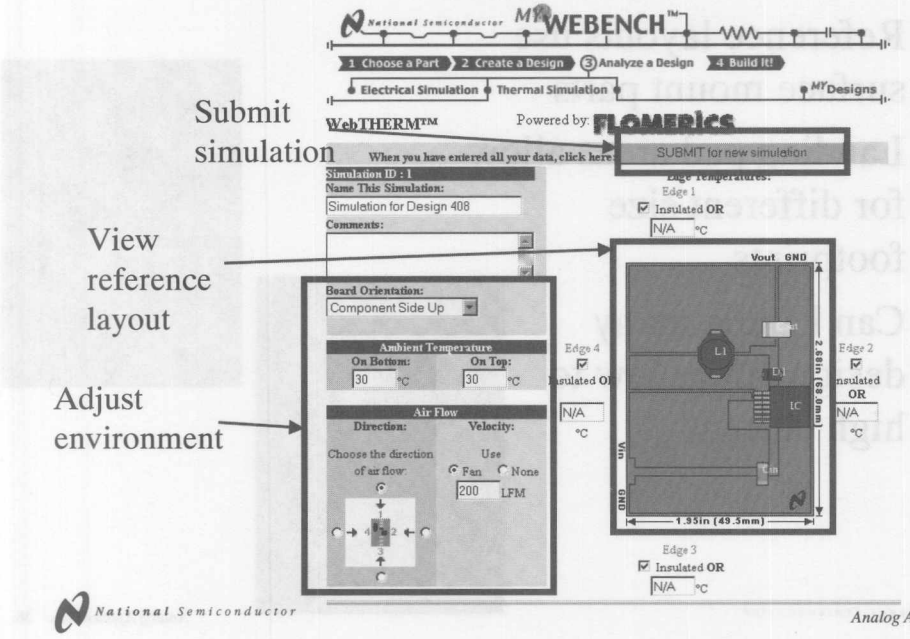
The simulation engine uses full 3D conduction and radiation solvers. Convection is modeled through correlations.

WebTHERM Value

- The Old Way: Theta-JA
 - Static value
 - Does not reflect environment
- With WebTHERM:
 - Approximate board-level analysis
 - Even more valuable for performing what-if type analyses
 - Changing airflow
 - Changing ambient conditions
 - Selecting alternate parts
 - Heat sinks

The traditional way of calculating the temperature of a part is using theta ja (or doing nothing at all). However, this technique does not necessarily take into account the interaction of parts on a board and it does not reflect the environmental conditions such as airflow. With WebTHERM, these interactions are taken into account. The tool is very useful for performing what if analysis for a design up front before constructing a prototype. Since the WebTHERM simulation engine does not use CFD at this time, the accuracy is limited to about 30%.

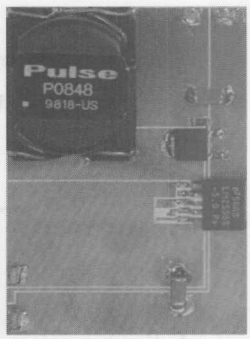
WebTHERM Inputs

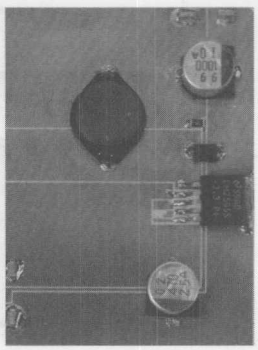


Webtherm uses the same tab oriented interface as WEBENCH. Here we are in the Boundaries step where we can view the reference printed circuit board layout, adjust the air flow velocity, adjust the top and bottom ambient temperatures and also specify the boundary temperatures. In addition we can enter the orientation of the board. There is also space for entering comments about the design.

Reference Boards

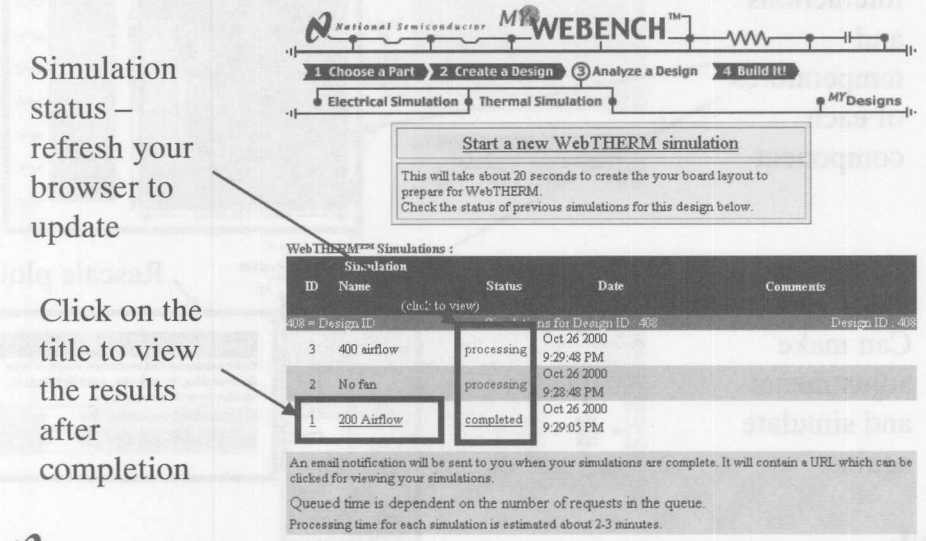
- Reference layouts use surface mount parts
- Landing pad areas allow for different size footprints
- Can handle many designs from low to high current



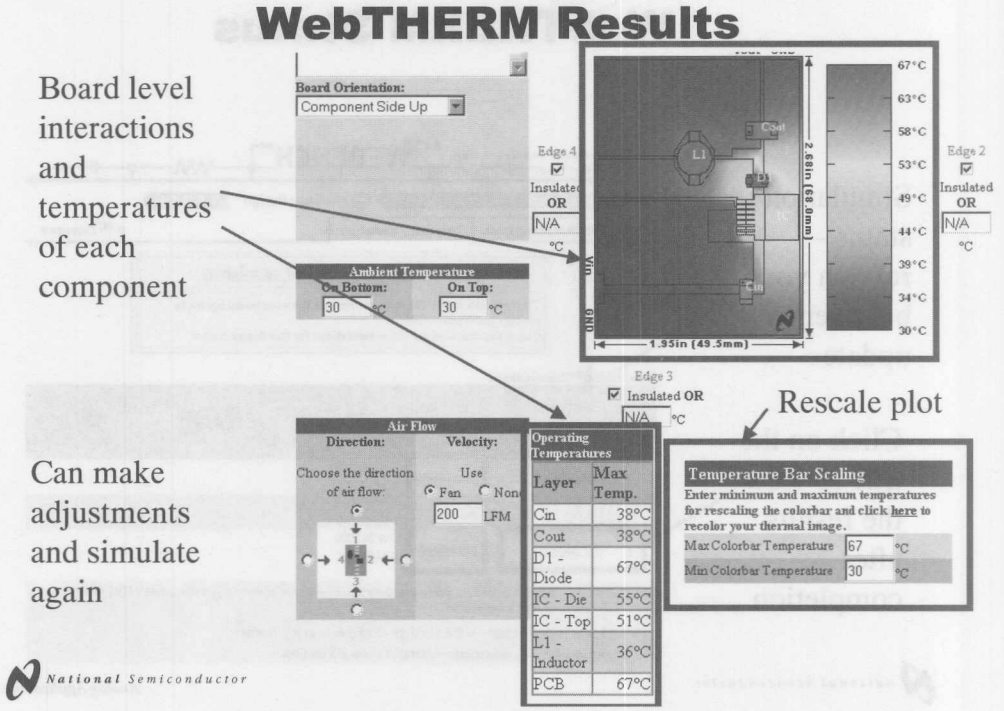


The reference layouts use landing pad areas which are sized to take surface mount components appropriate for the voltage regulator. The board can be trimmed down to accommodate a design with closely spaced parts if desired.

WebTHERM Status

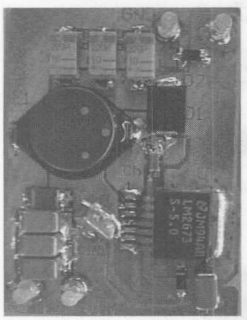


This is the WebTHERM simulation status page. The job status is shown along with the simulation title and time. The status is either queued, processing or completed. WebTHERM simulations typically take about 2 to 3 minutes excluding queue time which is dependent on system load. When the simulation status shows completed, you may click on the simulation title to view the results.



This is the last step in the thermal simulation process. It shows a color map of the temperatures across the PC board. It also indicates the temperature of each component. In this case, all the temperatures are within specification with 200 LFM airflow. The diode is the hottest part on the board which is typical for buck designs with a large difference between the input and output voltages. The plot can be rescaled to match other simulations, if desired. The user can go back and adjust the environmental variables or change the operating conditions of the design to improve the behavior if necessary. This can save a lot of time by reducing the number of iterations in the temperature lab.

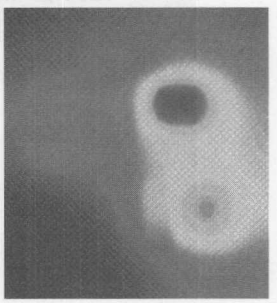
WebTHERM Test Run



Test Board



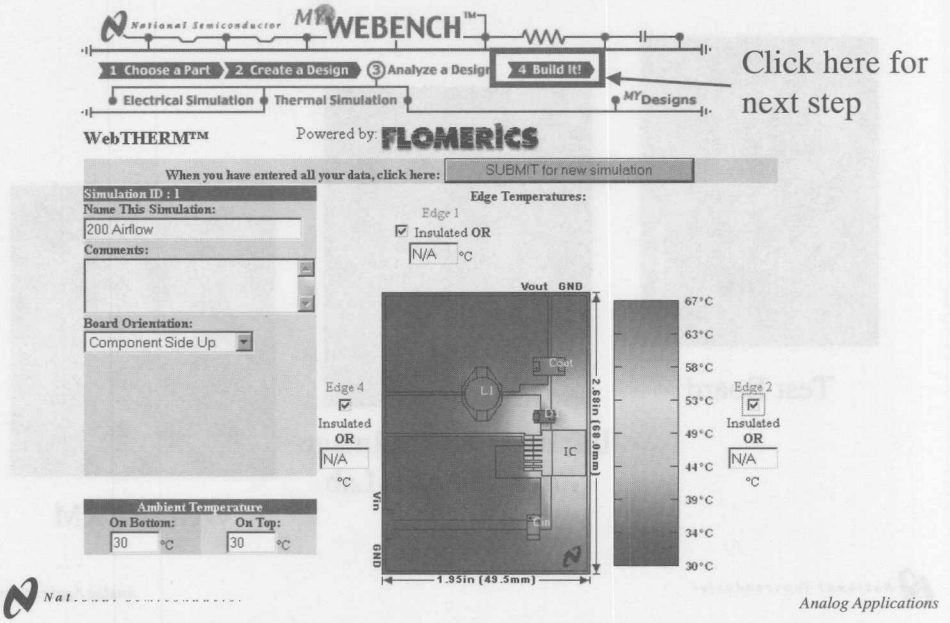
Infrared Camera Image
From Thermal Lab



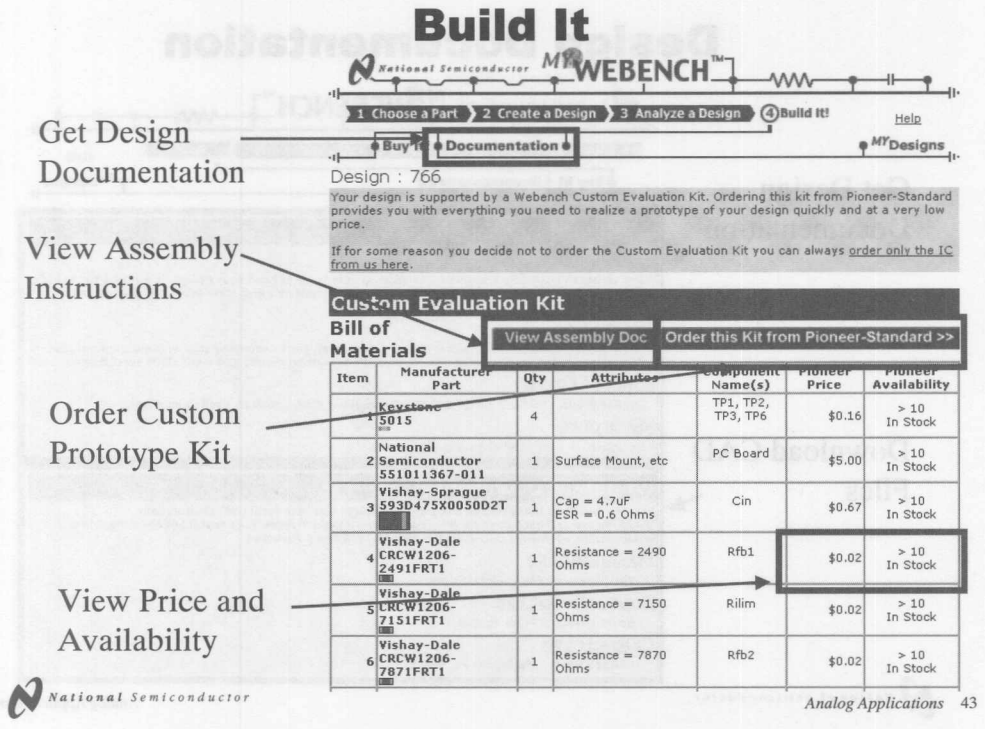
WebTHERM

This shows a verification run comparing the test board layout, infrared camera image and a WebTHERM verification plot. WebTHERM results are typically within 30% of the test board.

Simulations Completed



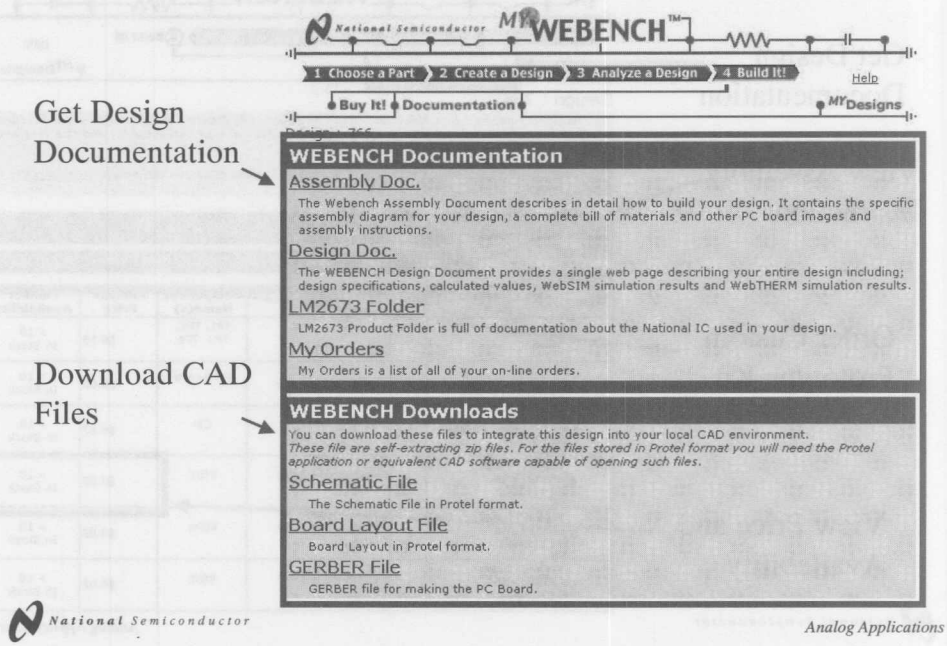
When the user is done analyzing the design, the Build It tab takes him or her to the last step of the process.



In the build it page, you can get started creating a prototype of your new design using the on line ordering system. The custom kit includes all the parts necessary to construct a prototype board for your design. This includes the National IC, passive components, a bare printed circuit board, and even test points and jumpers.

You can see if the parts are in stock in the Pioneer-Standard warehouse and get pricing information. You can also view an assembly diagram for the board and get instructions for building it by clicking of the View Assembly Document button. Further documentation is available including a summary of your simulations and downloadable schematic, layout and Gerber files under the Documentation tab. When you are finished reviewing the bill of materials, click on the Order this Kit from Pioneer-Standard button to be transferred seamlessly to the Pioneer-Standard web site.

Design Documentation



In the documentation page of Build It, you can view the assembly document which contains information for constructing your power supply. This includes an assembly diagram, schematic, bill of materials and instructions for building and testing the power supply.

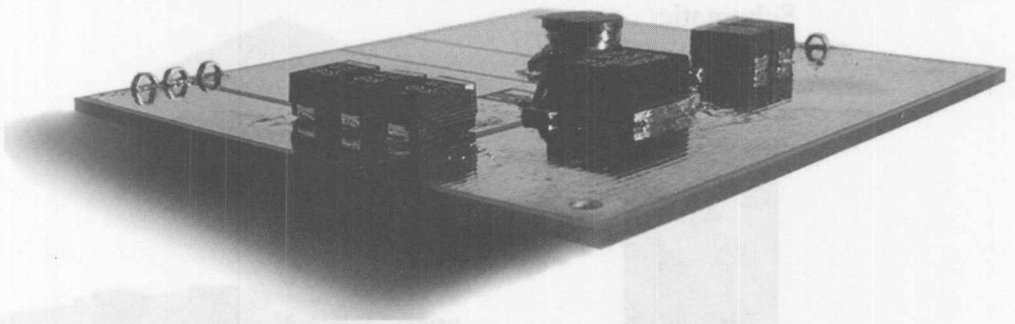
From the Design Doc link you can also get full documentation of the design including the specifications, operating values and thermal simulation results.

A detailed summary of the integrated circuit with links to the datasheet and application notes is in the Product Folder.

My orders shows your custom power supply kit order status and history.

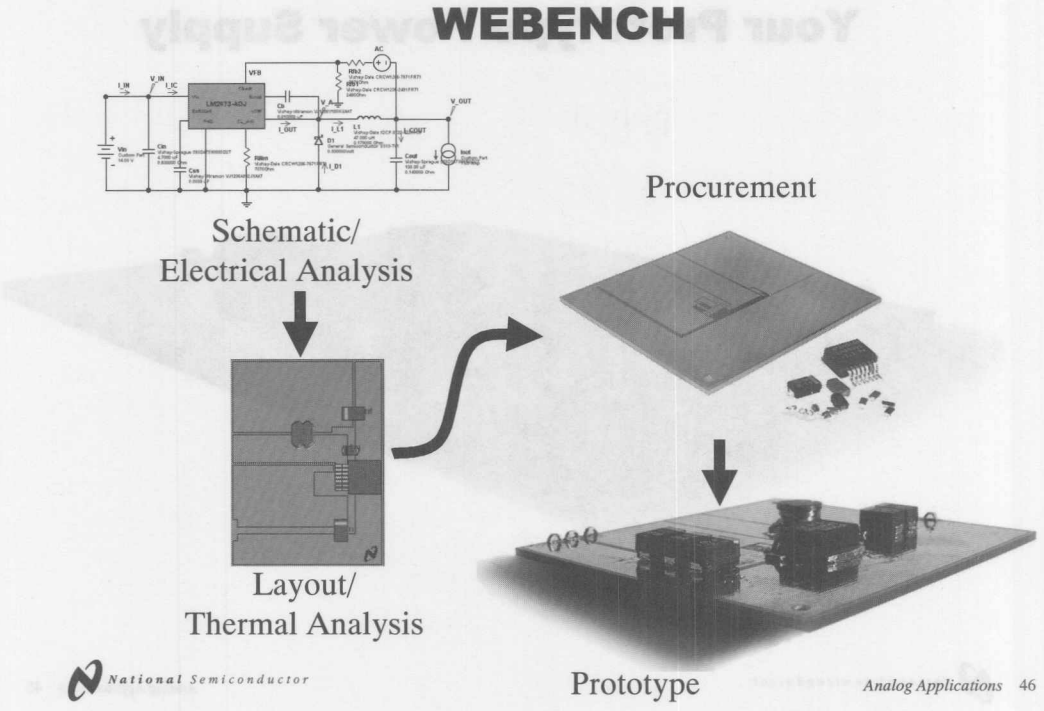
Downloadable schematic, layout and Gerber files are also available on this page. The schematic and layout files are in Protel format, so you must have Protel software or other software which can read the Protel file format to take advantage of these. The Gerber file is for the custom board used for this design.

Your Prototype Power Supply



Following the assembly instructions from the web, you will be able to construct and test your prototype power supply board quickly and easily. Thus you can see how WEBENCH saves you time and allows you to avoid costly mistakes by doing optimization up front in the design process, and then closes the loop by allowing you to to construct an actual prototype in record time.

WEBENCH redefines the way electrical design is done by using the power of the internet to save you time. Today it is more important than ever for designers to get their products to market fast and WEBENCH fulfills that need by providing you with a complete start to finish solution.



WEBENCH takes you through the entire design process from start to finish. Beginning with parts selection, to schematic generation, electrical simulation, layout generation, thermal simulation and prototype kit procurement, you get the finished prototype faster than ever.

Conclusions

- On line power supply design and simulation is powerful and easy to use
- WebSIM provides information about electrical behavior of circuit
- WebTHERM identifies temperature problems in PC board
- Build It accelerates prototype construction
- WEBENCH shaves significant time off the design cycle
- Use POWER.NATIONAL.COM for your next design

WEBENCH is powerful and easy to use software for designing power supplies. Give it a try for your next design.

Design Your Phase-Locked Loop

Circuit Online at

WIRELESS.NATIONAL.COM



Internet Marketing Manager – National's contact for web-based Wireless design community

Seminar Outline

- Wireless Site Overview
- WEBENCH™2.0– EasyPLL Overview
- EasyPLL Demonstration
- Questions & Answers

Seminar presentation will briefly cover Wireless site, but will focus on EasyPLL simulation tools and how to use them.

WIRELESS.NATIONAL.COM

Goal

Create a highly productive design experience that saves our customers time

Objective

Get to product or reference design as quickly as possible

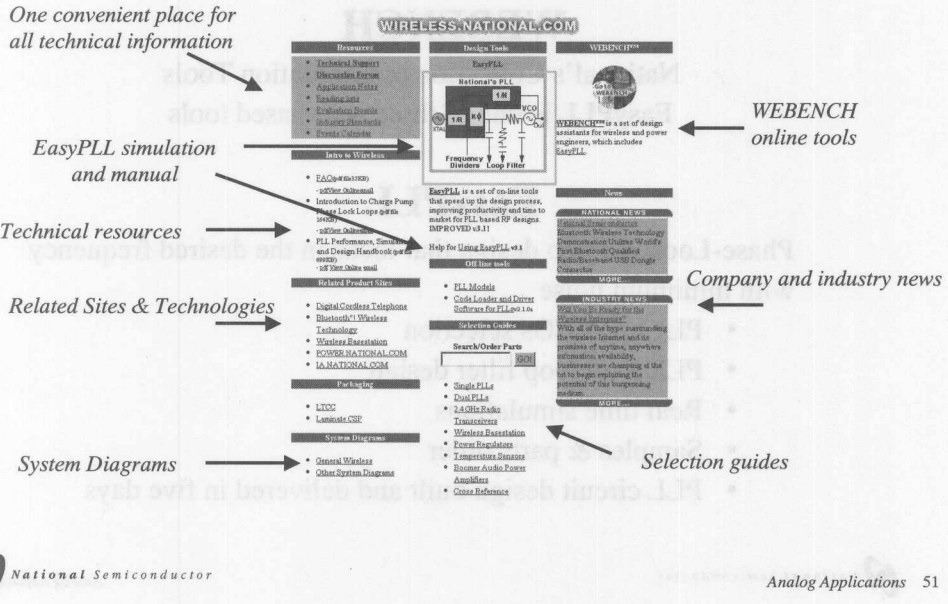
Goal for Wireless site is to make the best use of the designers' time – so more time to do 'other' things

National wants to provide the designers with tools and information that will get them the products or reference designs as quickly as possible.

The Wireless site features a collection of all National's tools and information for the Wireless design community such as:

- Technical Resources
- Discussion Forum
- Product Selection Guides
- Application Notes
- System Diagrams
- National & Industry News
- WEBENCHTM2.0 – EasyPLL Simulation

WIRELESS.NATIONAL.COM



Website is designed for quick access to information.

Though are several ways to access EasyPLL; however, WIRELESS.NATIONAL.COM is the most common way.

WEBENCHTM - EasyPLL

WEBENCH

National's Collection of Simulation Tools
EasyPLL is one of three web-based tools

EasyPLL

Phase-Locked Loop design that locks in the desired frequency with minimum noise

- PLLs & VCOs selection
- PLL with loop filter design
- Real time simulations
- Samples & parts order
- PLL circuit design built and delivered in five days

EasyPLL is one of three simulation tools available within WEBENCH.

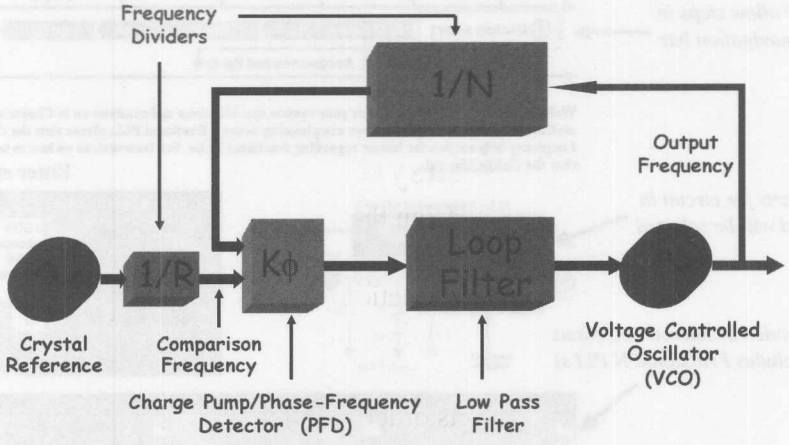
The Phase-Locked Loop circuit is important because in applications such as cell phones, you want a good connection by staying locked on to the carrier frequency with as little noise as possible.

EasyPLL flows from parts selection to analysis, finally to product purchase

Note: PLL → Phase-Locked Loop

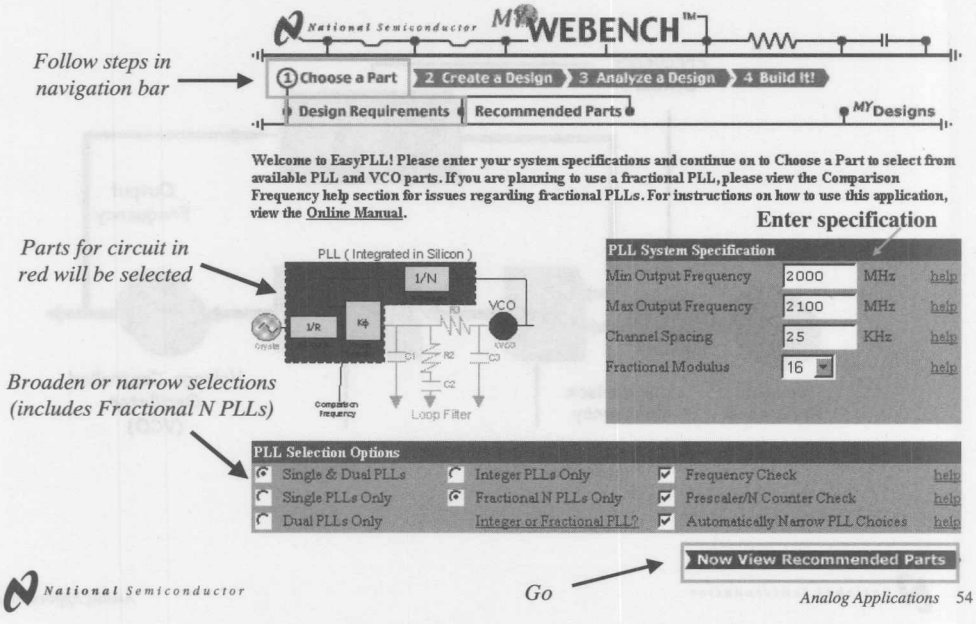
VCO → Voltage Controlled Oscillator

Phase-Locked Loop Circuit



PLL circuit is shown to provide a better understanding of the information required in performing the simulation

Choose a Part



The navigation bar provides easy process flow for simulation

Choose a Part – provides assistance in selecting NSC PLL and optional VCO

Portions of circuit in red are the functions for the parts to be selected

Enter frequency specifications

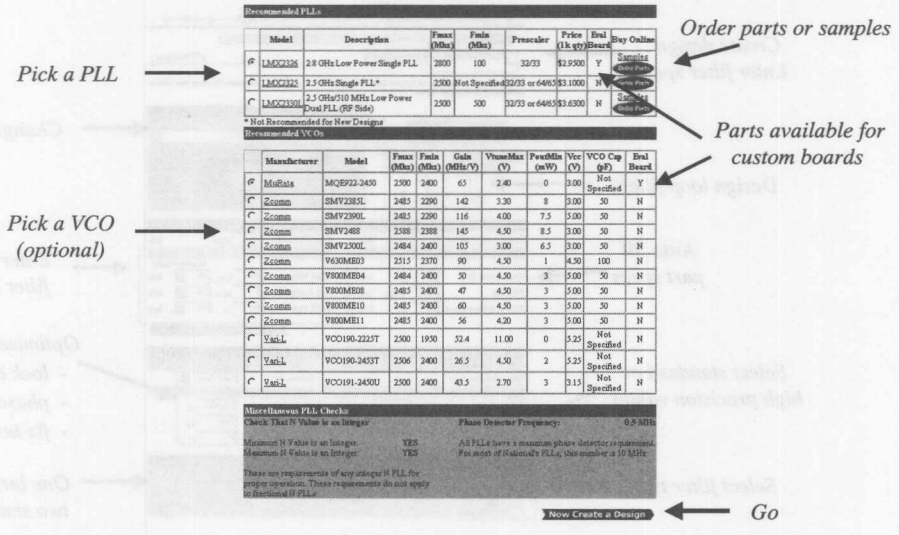
Note: NSC PLLs frequency range is 25MHz to 2.8MHz

User can broaden or narrow the list of parts presented

Included in simulation are the fractional N PLLs

Go to next step by clicking Now View Recommended Parts

Cost Benefit Analysis



List of PLLs and VCOs that meet the specifications are presented

A cost benefit analysis can be performed since the key parameters and pricing info are available

- clicking part number links to product folders
- clicking 'Samples' links to National's ordering page for limited free samples
- clicking 'Order Parts' links to distribution list for ordering parts

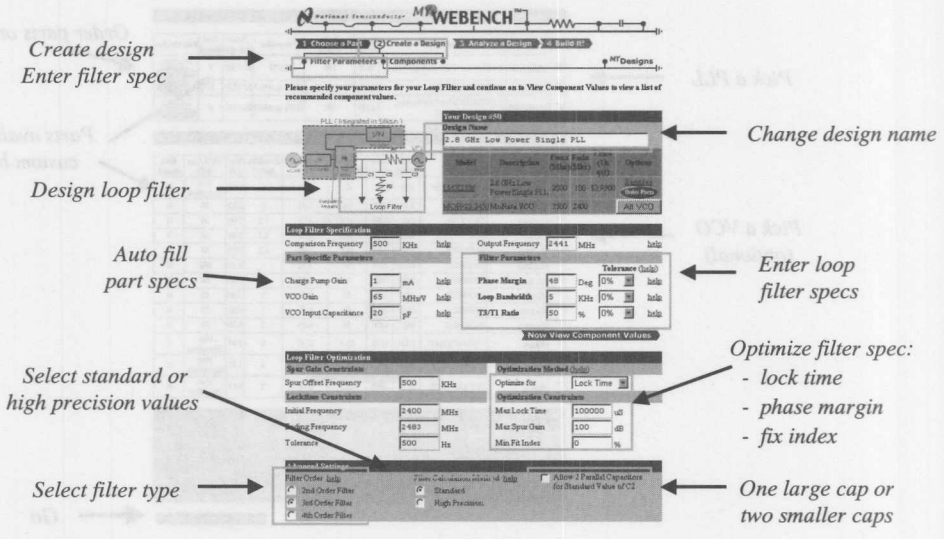
User must select a PLL but have the option of selecting a VCO

Table indicates the PLL and VCO available to build a custom board

The specifications can be changed to provide a new list of parts.

Click 'Create a New Design' to move to the next step.

Create a Design



Now that the PLL and optional VCO have been selected, the user now can design the appropriate loop filter which is highlighted in red. Selecting 2nd, 3rd, or 4th order filter will change the circuit accordingly.

The design name can be changed if the default value is not acceptable, the loop filter specifications are pre-filled with the appropriate values of the selected PLL & VCO

Enter the loop filter specs under the Filter Parameters - phase margin, loop bandwidth, T2/T1, T3/T1 ratio.

Also available is the selection of filter calculation method, either standard or ultimate

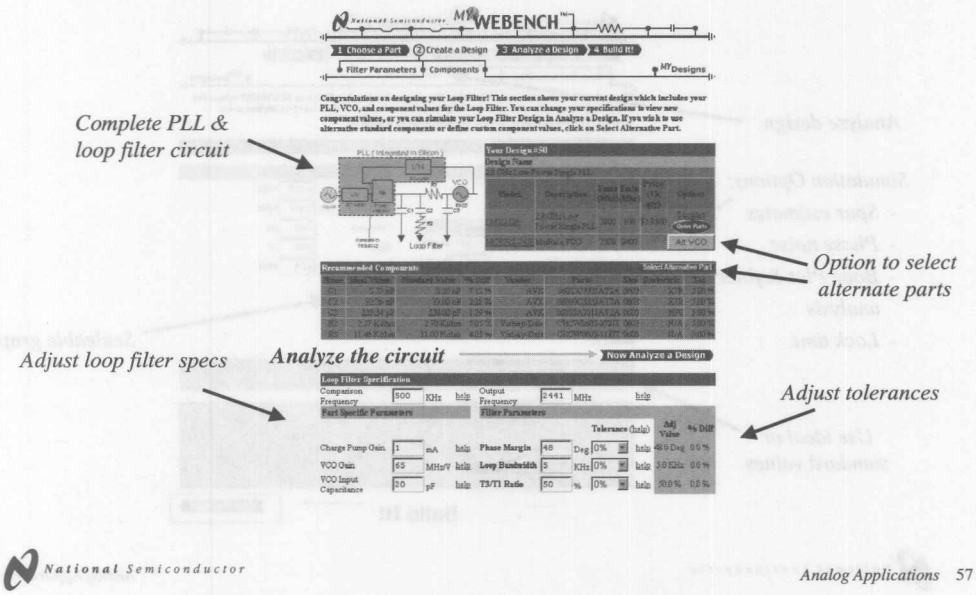
standard – only component values readily available

ultimate – calculated values used

The loop filter parameters can be designed tight, 0%, or with some variations. The loop filter can be optimized with respect to lock time, spur gain, or fix index.

The user also has the option of using one large capacitor, C2, or two smaller parallel capacitors.

Review Selections



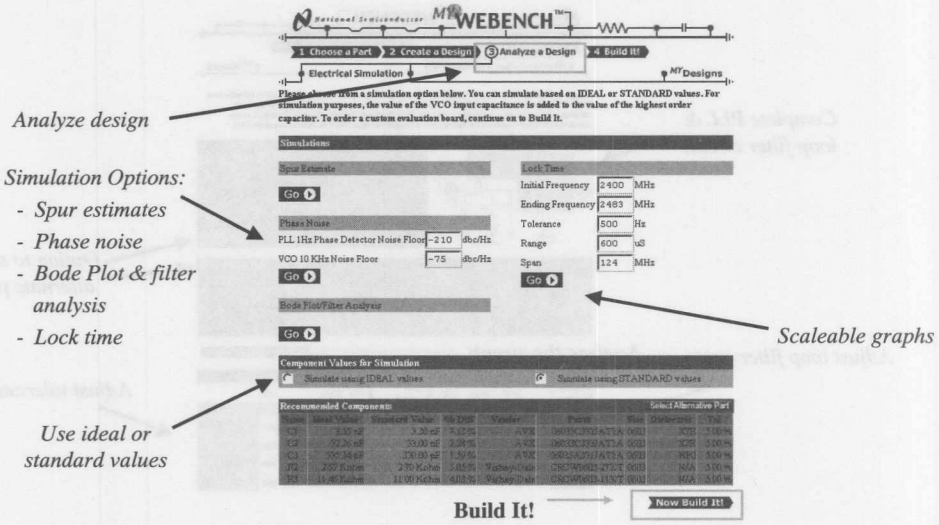
The complete PLL and loop filter design with the recommended components are listed.

If components from other manufacturers or slightly different values are preferred, alternate parts can be selected.

Parameters tolerance can be adjusted to meet design requirements.

Now, we're ready to analyze the design

Analyze the Design



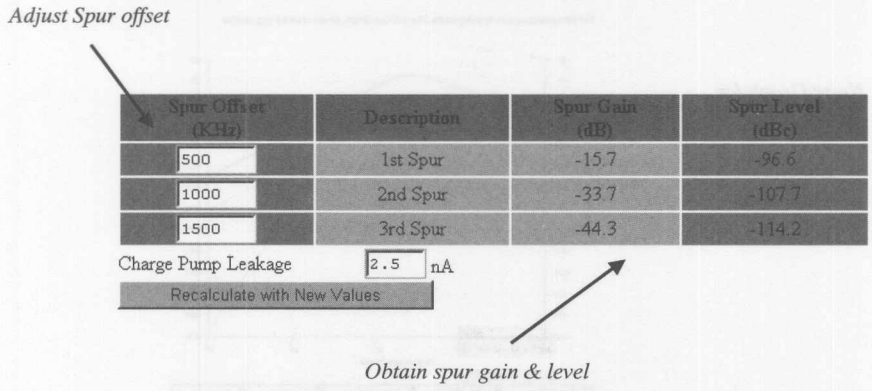
Several simulations are available

- spur characteristics
- phase noise
- Bode plots and filter analysis
- lock time

Both the Bode plots and lock time graphs can be rescaled as needed.

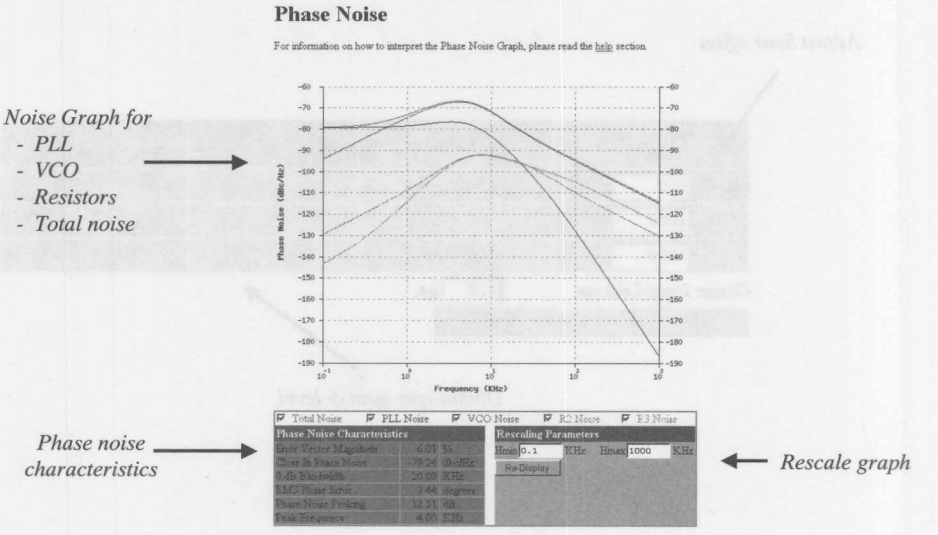
Examples of the above simulations are shown on the next few slides.

Spur Estimate



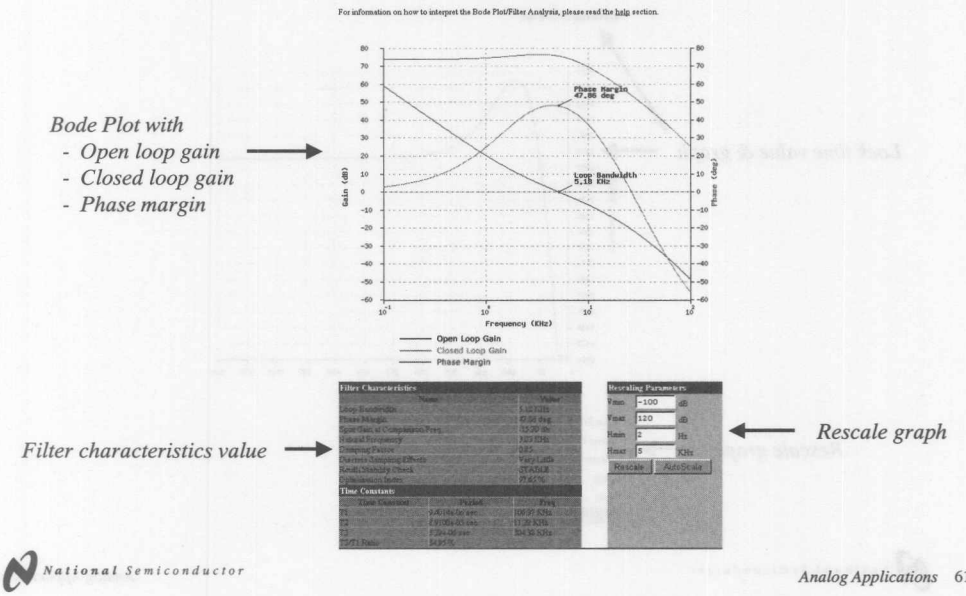
Spur offset can be adjusted. Corresponding spur gain and spur level are displayed

Phase Noise Simulation



The phase noise graph is displayed along with the table of values. The graph can be rescaled.

Bode Plot Simulation

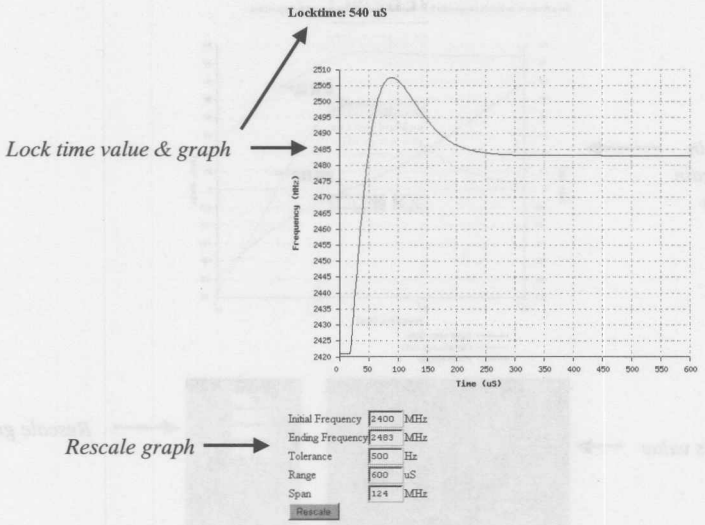


On the Bode plots, the gains and phase margin are overlayed on the graph.

Also, the critical points on the graphs are presented in a table along with the optimization index indicating how optimized the loop filter is

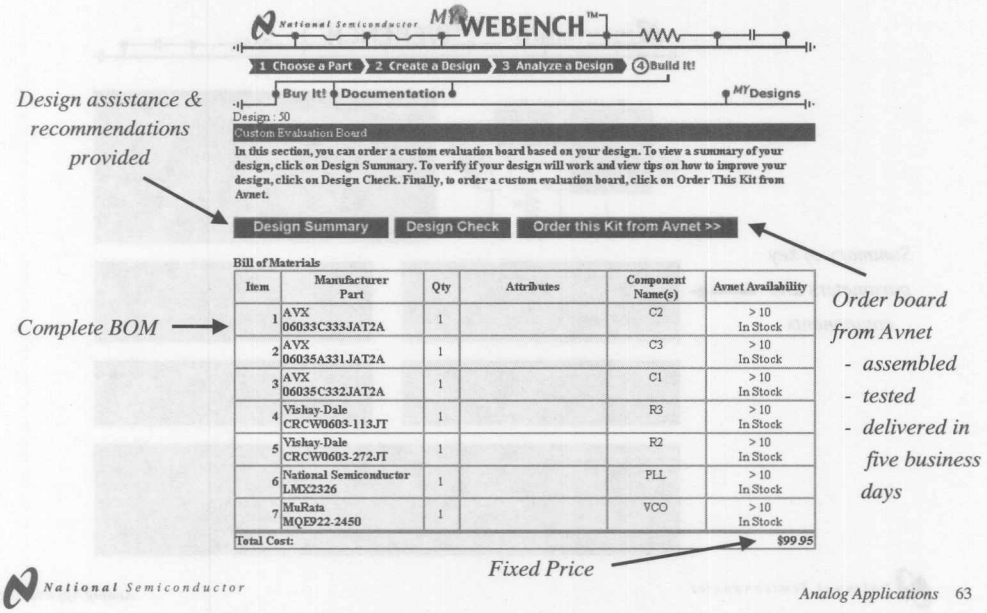
The graph can be rescaled as needed

Lock Time Simulation



The lock time value and graph are also presented. The graph can be rescaled.

Build It!



Design assistance & recommendations provided

Complete BOM

Order board from Avnet
- *assembled*
- *tested*
- *delivered in five business days*

Fixed Price

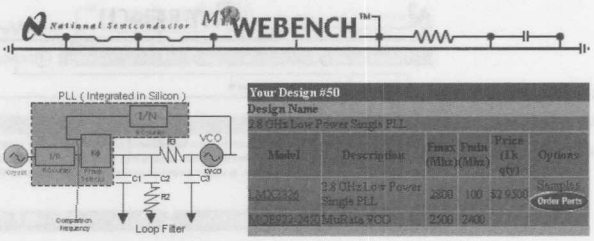
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After the design and analysis are completed, the complete Bill of Materials is presented.

Design summary and design check provides assistance to the user

Clicking 'Order board from Avnet' sends user to page with instructions for ordering boards on Avnet's site. Avnet will accept orders, assemble, test, and deliver custom boards within 5 business days worldwide.

Design Summary



Summary of key parameters and components

Your Design #50

Design Name

2.8 GHz Low Power Single PLL

Model	Description	Fmax (Mhz)	Fstep (Mhz)	Price (1k qty)	Options
LMX2326	2.8 GHz Low Power Single PLL	2800	100	$2.9308	Samples, Order Parts
MQE972-2450	MuRata VCO	2500	2400		

System Specification Parameters

Min Output Frequency	2400	MHz
Max Output Frequency	2483	MHz
Comparison Frequency	200	KHz

Loop Filter Specification Parameters

Output Frequency	2441	MHz
Phase Margin	48	Degrees
Loop Bandwidth	5	KHz
C3/C1 Ratio	50	%

Part Specific Parameters

Charge Pump Gain	1	ma/2pi rad
VCO Gain	65	MHz/V
VCO Input Capacitance	20	pF

Achieved Filter Optimization Values

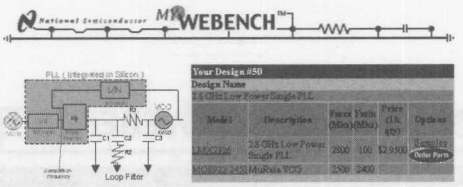
Lock Time	570.8	uS
Spur Gain	16.3	dB
Fit Index	88.0	%

Recommended Components

Name	Ideal Value	Standard Value	% Diff	Vendor	Part#	Size	Dielectric	Tol
C1	7.55 nF	7.50 nF	7.13 %	AVX	06031C332JAT2A	0603	X7R	5.00 %
C2	32.26 nF	33.00 nF	2.28 %	AVX	06033C333JAT2A	0603	X7R	5.00 %
C3	332.34 pF	330.00 pF	1.59 %	AVX	06035A331JAT2A	0603	NP0	5.00 %
R2	2.57 Kohm	2.70 Kohm	5.05 %	Vishay-Dale	CRCW0603-272JT	0603	N/A	5.00 %
R3	11.46 Kohm	11.00 Kohm	4.03 %	Vishay-Dale	CRCW0603-113JT	0603	N/A	5.00 %

The specifications used for the design are summarized in several tables. The recommended components are also displayed again.

Design Check



Detailed design checks with assistance, tips, and recommendations →

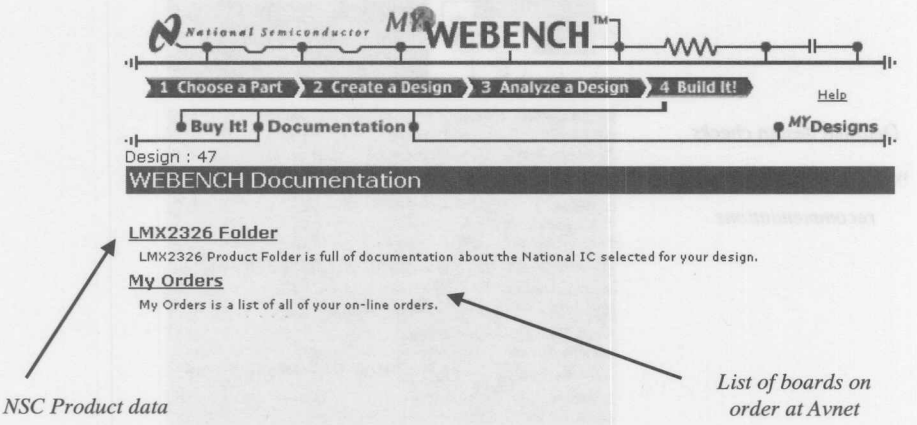
Design Check	Result	Comments
VCO Type Check	Ok	No Comments
VCO Capacitance Check	Ok	No Comments
VCO Voltage Check	Ok	No Comments
VCO Output Power Check	Ok	No Comments
PLL Type Check	Ok	No Comments
PLL Max Frequency Check	Ok	No Comments
PLL Min Frequency Check	Ok	No Comments
Capacitor Dielectric Check		X7R dielectrics are the worst performance dielectric EasyPLL uses. NP0/C0G are the best performance dielectrics.
Capacitor Footprint Check	Ok	No Comments
Discrete Sampling Effects Check	Ok	No Comments
Routh Stability Check	Ok	No Comments
Optimization Index Check	Ok	No Comments
Low Filter Order Check		Increasing the filter order by one can provide at least 5 dB of spur level reduction.
High Filter Order Check	Ok	No Comments
Phase Margin Check	Ok	No Comments
Custom Component Check	Ok	No Comments
Supported Component Check	Ok	No Comments
Part Specific Parameter Check	Ok	No Comments

Before order is fulfilled, a comprehensive design check is provided. Also provided are tips and recommendation for optimized design.

Major failures will prevent continuation of the ordering process until resolved.

Once failures are resolved, then user enters Avnet's shopping cart where registration is required.

Build It! Documentation

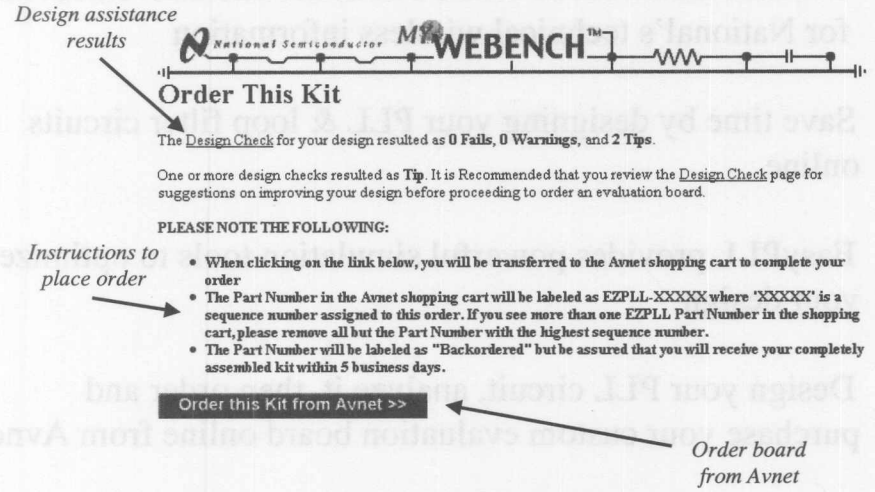


NSC Product data

List of boards on order at Avnet

Documentation on the NSC part is provided along with the list of boards on order at Avnet.

Order the Board



Instructions for ordering the boards before going to Avnet's site are displayed along with the design assistance results.

Ordering the boards will take the user into Avnet's shopping cart. There they will have to log on Avnet's site and register. Avnet then assembles, test, and deliver the custom boards to the users. They also send the user confirmation emails and shipping and tracking information.

Conclusion

- WIRELESS.NATIONAL.COM is the one convenient site for National's technical wireless information
- Save time by designing your PLL & loop filter circuits online
- EasyPLL provides powerful simulation tools to optimize your design
- Design your PLL circuit, analyze it, then order and purchase your custom evaluation board online from Avnet

WIRELESS.NATIONAL.COM provides one-stop shop for National's complete wireless solution

EasyPLL is a simple but powerful web-based tool that allows designers to save time when designing and optimizing PLL & loop filter circuits online.

Users are able to design, analyze, and now order and purchase custom evaluation boards online through Avnet

POWER.NATIONAL.COM

Appendix

Technical Case Studies



Seminar Outline

- Technical case studies of power supply design using WEBENCH 2.0
- Question and answer

In this seminar we will present several examples of how WEBENCH can be used to design a power supply on the internet.

Technical Case Studies

- Step down regulator
 - Effect of diode voltage drop on temperature
- Boost topology
 - Look at effect of boost input voltage vs maximum switch current
 - Thermal considerations
- 3 output flyback topology
 - Examine cross regulation effects

The three examples we will present are:

1) A step down regulator in which we examine the effect of the diode voltage drop on the temperatures across the board.

2) A boost topology design in which we look at the difference between the input and output voltage and the effects on switch current and temperature

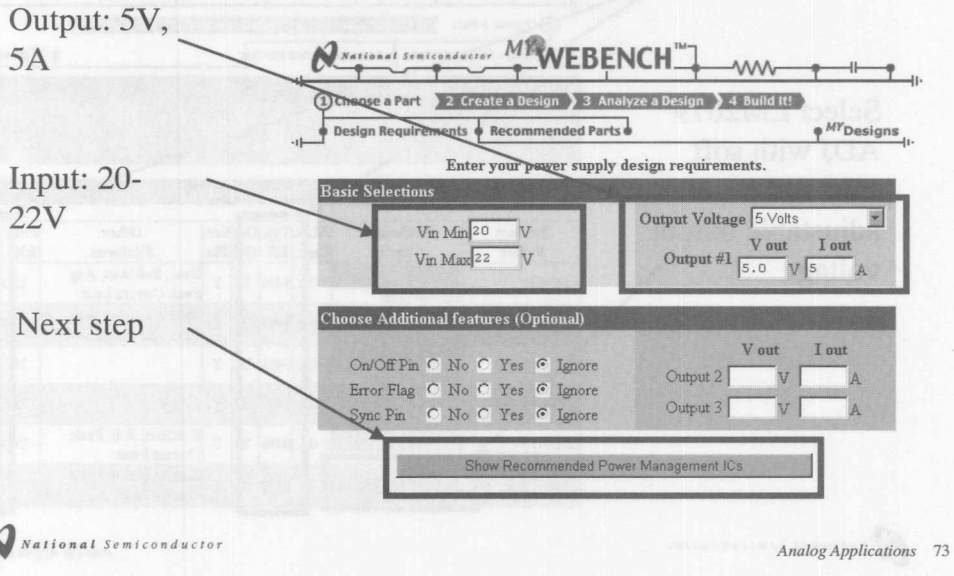
3) A three output flyback topology where we test the cross regulation effect of one output on the other two outputs.

Example 1: Step Down Voltage Regulator

- Create design using 20 – 22V input and 5V, 5A output
- This is a high current design which can put thermal stress on the diode in the circuit

The first example is a step down design using 20 to 22V input and 5V, 5A output.

Enter Requirements



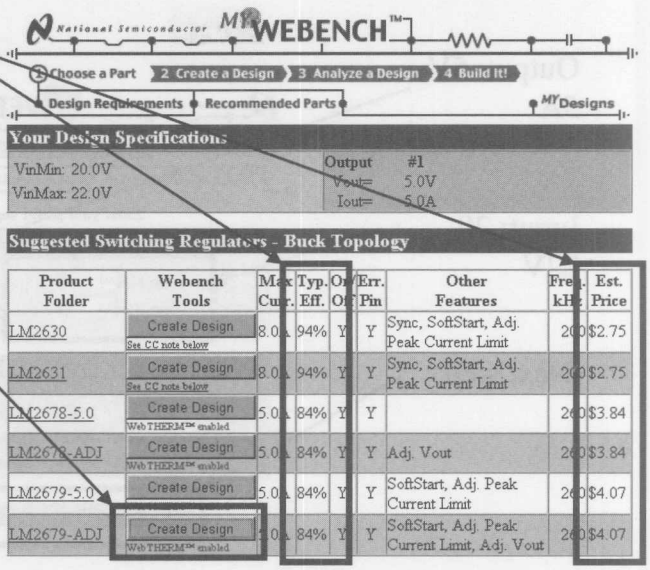
We are in step 1 of the WEBENCH power supply design process, Choose a Part. This is indicated near the top of the page where you can see the WEBENCH navigation bar. The four steps to design a power supply are listed, with the currently active step highlighted in red. You can go immediately to another step by clicking on it if it is bright blue. If it is gray-blue, then the step is not currently accessible. Since we have not yet entered the specifications for our design, no other steps are accessible yet.

Below the WEBENCH navigation bar, you can see that the Design Requirements tab is highlighted. Here you enter the power supply design requirements. Vin: 20 to 22V, Vout: 5V, Iout: 5A. Click on the Show Recommended Power Management ICs button at the bottom of the page to go to the next step.

Choose a part

Make tradeoffs

Select LM2679 ADJ with soft start and adjustable output voltage



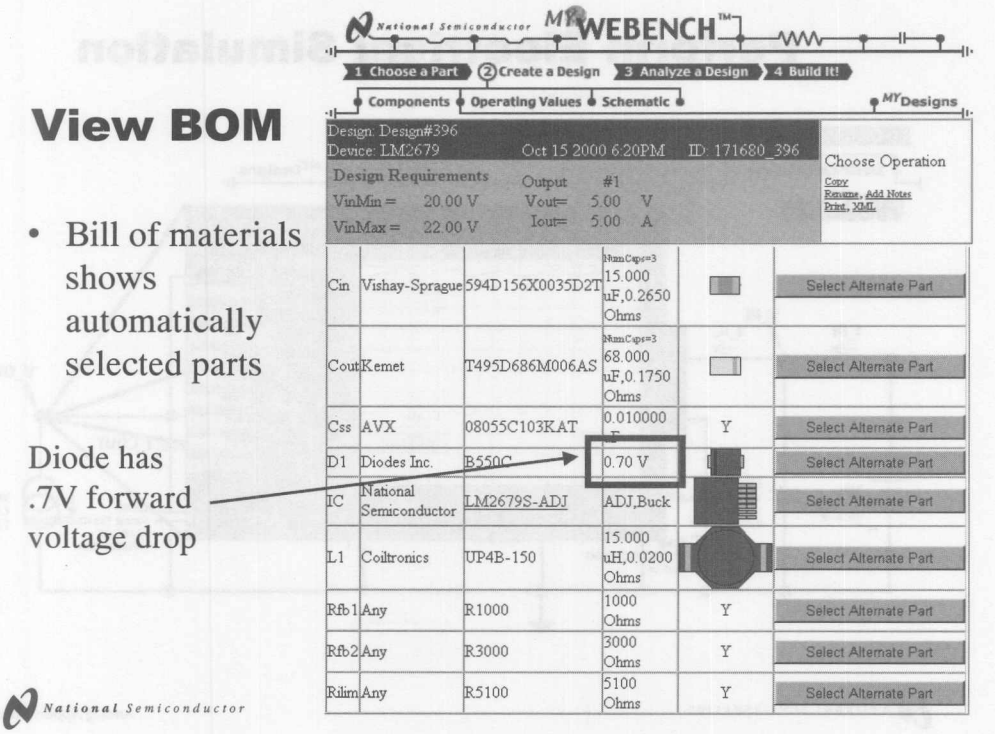
We are now in the Recommended Parts page of the Choose a Part step. This page shows the recommended parts along with tradeoffs such as price, efficiency and features. Click on the Product Folder link in the left column to access a datasheet and other detailed information about a part.

For this design, we select the LM2679 simple switcher regulator with soft start, adjustable peak current limit and adjustable output voltage.

View BOM

- Bill of materials shows automatically selected parts

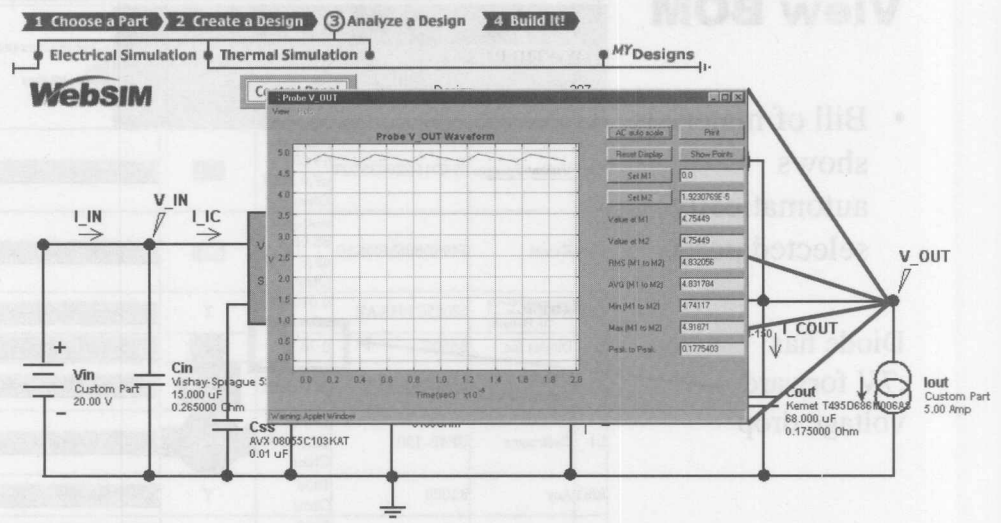
Diode has .7V forward voltage drop



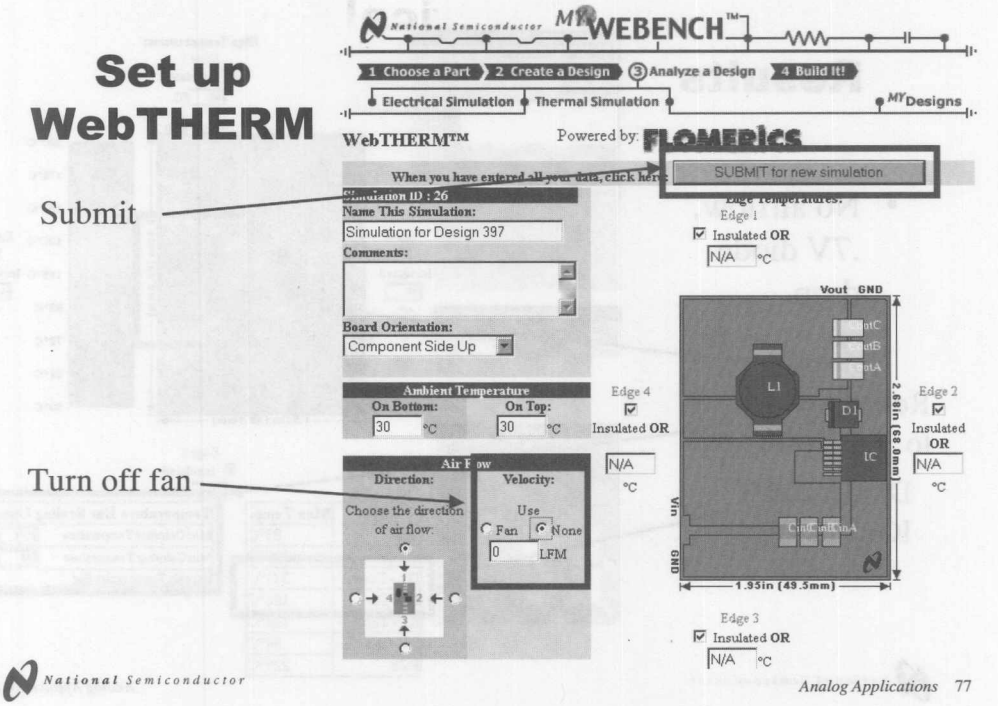
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Now we are in step 2 of the design process, Create a Design. Here we can view the bill of materials including the reference designator, manufacturer, part number, part attributes, scaled part outline drawing and a button to select alternate parts.

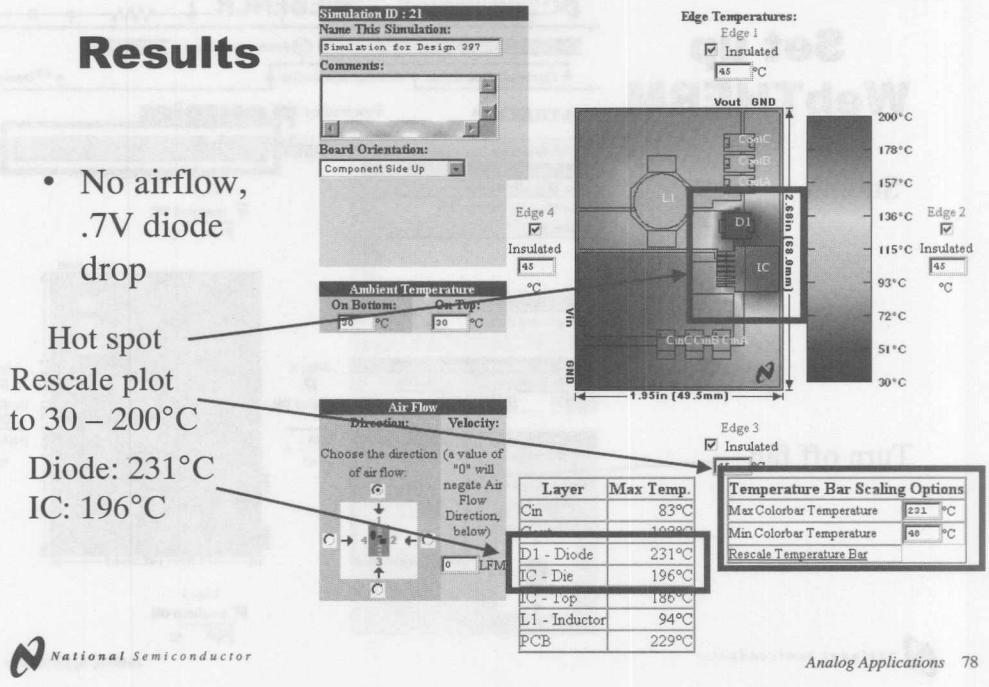
We see that the diode for this design has a .7V forward voltage drop.



Now we go into step 3 of the design process, Analyze a Design by clicking on the WEBENCH header. We enter WebSIM by clicking on the Electrical Simulation tab and run a steady state electrical simulation. We click on the V_OUT node in the circuit to verify that the output ripple is OK for this design.



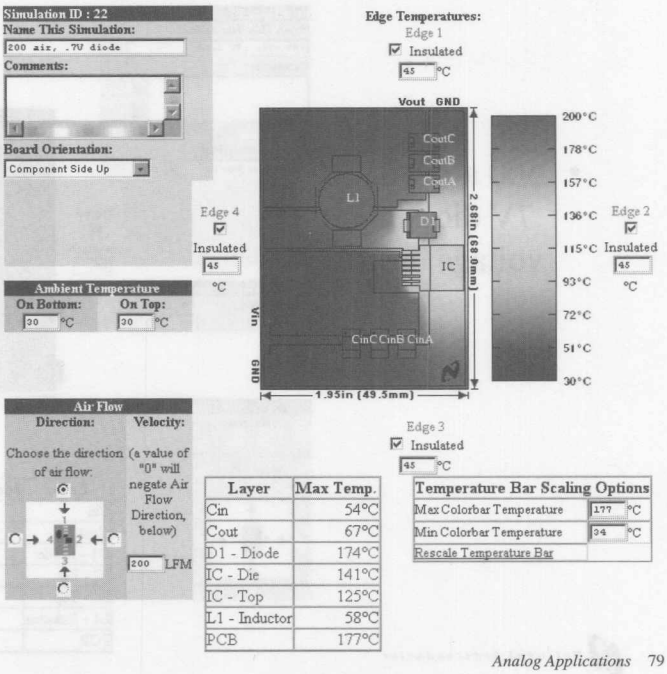
Next we click on the thermal simulation tab to enter WebTHERM. We start out by turning off the fan and clicking on the SUBMIT for new simulation button to start the simulation.



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After 2 or 3 minutes, the simulation is ready. We open the simulation results and see that this design generates a lot of heat. The diode is the hottest part at 231°C with the IC close behind at 196°C. We rescale the plot to go from 30°C to 200°C using the Temperature Bar Scaling Options in the lower right portion of the screen. This way we can easily compare this result with other simulations. After rescaling, we print out the results using the browsers print function. Next we change the air flow to 200 linear feet per minute and resubmit the simulation. While we are waiting for this simulation to complete, we start 2 more simulations, one at 500 LFM air flow, and another at 1000 LFM air flow.

- 200 airflow, .7V diode drop

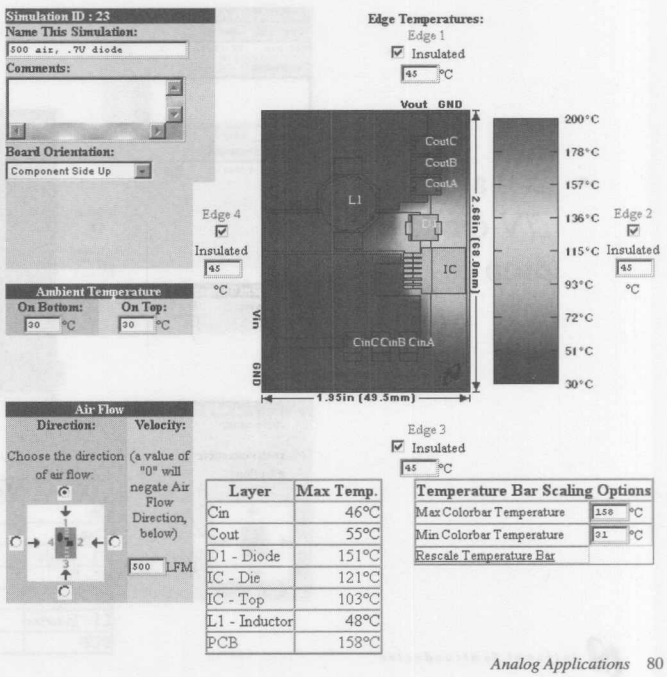


Layer	Max Temp.
Cin	54°C
Cout	67°C
D1 - Diode	174°C
IC - Die	141°C
IC - Top	125°C
L1 - Inductor	58°C
PCB	177°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	177 °C
Min Colorbar Temperature	94 °C
Rescale Temperature Bar	

Here are the results from the simulation using 200 LFM air flow. The temperatures of the components have dropped, but are still too high.

- 500 airflow, .7V diode voltage drop

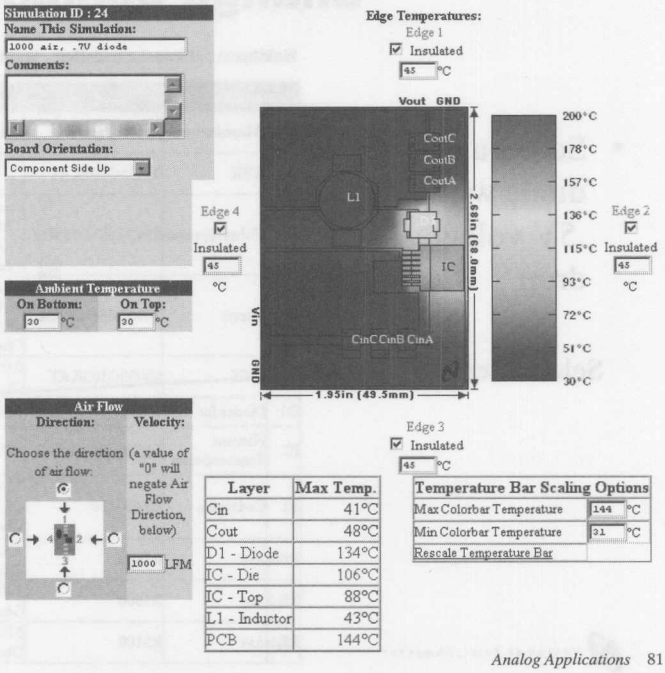


Layer	Max Temp.
Cin	46°C
Cout	55°C
D1 - Diode	151°C
IC - Die	121°C
IC - Top	103°C
L1 - Inductor	48°C
PCB	158°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	158 °C
Min Colorbar Temperature	91 °C
Rescale Temperature Bar	

Here are the results using 500 LFM air flow. The results are marginal.

- 1000 airflow, .7V diode voltage drop



Layer	Max Temp.
Cin	41°C
Cout	48°C
D1 - Diode	134°C
IC - Die	106°C
IC - Top	88°C
L1 - Inductor	43°C
PCB	144°C

Here are the results using 1000 LFM air flow. The temperatures are now acceptable, but the air flow is too high. So we will try changing the diode to one with lower voltage drop.

Change component

- Select a new diode with .5V voltage drop

Select alternate part

Webtherm - Thermal Simulation Websim - Electrical Simulation

Components

Part	Manufacturer	Part#	Attributes	Thermally Modelled*	
Cb	AVX	08055C103KAT	0.010000 uF	Y	Select Alternate Part
Cin	Vishay-Sprague	594D156X0035D2T	NumCaps=3 15.000 uF,0.2650 Ohms		Select Alternate Part
Cout	Kemet	T495D686M006AS	NumCaps=3 68.000 uF,0.1750 Ohms		Select Alternate Part
Css	AVX	08055C103KAT	0.010000 uF	Y	Select Alternate Part
D1	Diodes Inc.	B550C	0.70 V		Select Alternate Part
IC	National Semiconductor	LM2679S-ADJ	ADJ,Buck		Select Alternate Part
L1	Coiltronics	UP4B-150	15.000 uH,0.0200 Ohms		Select Alternate Part
Rfb1	Any	R1000	1000 Ohms	Y	Select Alternate Part
Rfb2	Any	R3000	3000 Ohms	Y	Select Alternate Part
Rilim	Any	R5100	5100 Ohms	Y	Select Alternate Part

National Semiconductor

We click on the Create a Design button in the WEBENCH header to view the bill of materials again. Then we click on the Select Alternate Part button for the diode.

Select Alternate

Select Alternate for Component D1

Please select from the list of available alternates below.
Click on the "Update BOM " button when you are done.

Update BOM

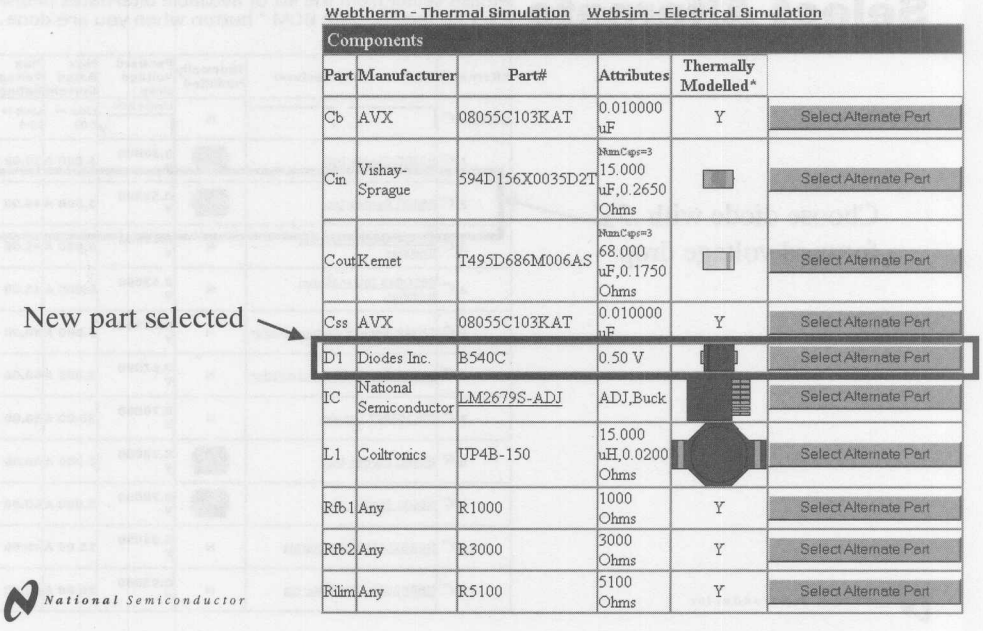
Alternates	Part #	Manufacturer	Thermally Modelled	Forward Voltage Drop	Max Rated Current	Max Voltage Rating	X,Y,Z in mm
Custom			N	Limit = 0.00 V	Limit >= 6.00	Limit >= 26.4	
1	B530C	Diodes Inc.	[redacted]	0.50000 V	5.000 A	30.00 V	8.13 6.22 2.6
2	B540C	Diodes Inc.	[redacted]	0.50000 V	5.000 A	40.00 V	8.13 6.22 2.6
3	[illegible]	Rectifier	N	[illegible] V	6.000 A	45.00 V	
4	80SQ045	International Rectifier	N	0.53000 V	8.000 A	45.00 V	
5	SB540	General Semiconductor	N	0.55000 V	5.000 A	40.00 V	
6	SB560	General Semiconductor	N	0.67000 V	5.000 A	60.00 V	
7	SBL3050PT	Lite-On	N	0.70000 V	30.00 A	50.00 V	
8	B550C	Diodes Inc.	[redacted]	0.70000 V	5.000 A	50.00 V	8.13 6.22 2.6
9	B560C	Diodes Inc.	[redacted]	0.70000 V	5.000 A	60.00 V	8.13 6.22 2.6
10	MBRB1545CTT4	Motorola	N	0.84000 V	15.00 A	45.00 V	
11	MBRB2060CTT4	Motorola	N	0.95000 V	20.00 A	60.00 V	

Choose diode with .5V forward voltage drop

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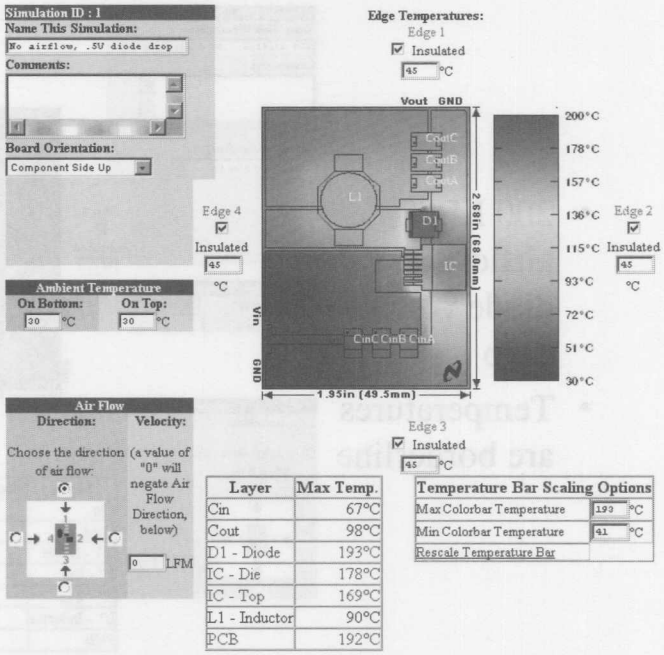
Here we see a list of suggested alternate parts for the diode. We choose a diode with .5V forward voltage drop by clicking on the radio button next to the part.

New component



We now see that the bill of materials has been updated. Next we do another set of thermal simulations using no air, 200 LFM, 500 LFM and 1000 LFM.

- No airflow, .5V diode voltage drop
- Diode temperature is 40°C cooler than for .7V diode due to less power dissipation

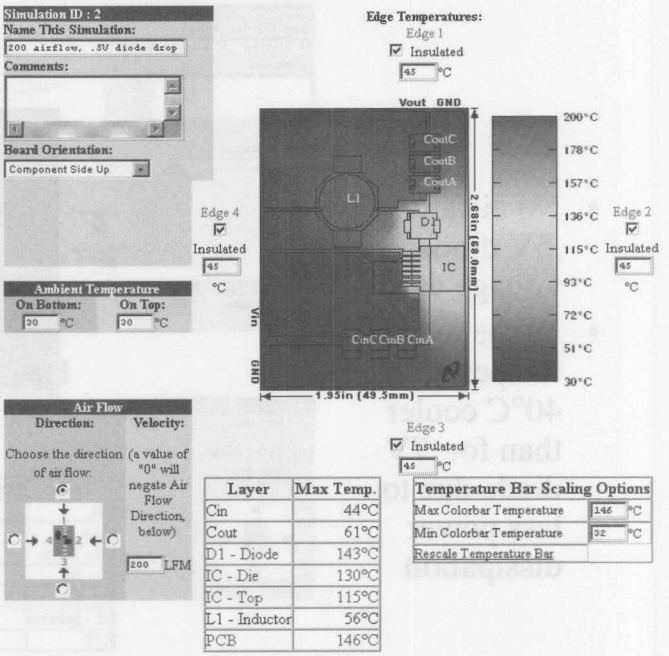


Layer	Max Temp.
Cin	67°C
Cout	98°C
D1 - Diode	193°C
IC - Die	178°C
IC - Top	169°C
L1 - Inductor	90°C
PCB	192°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	193 °C
Min Colorbar Temperature	41 °C
Rescale Temperature Bar	

With the new diode with lower voltage drop, the diode temperature is now about 40°C cooler than it was. The IC temperature has also dropped. However, without a fan, the diode and IC temperatures are still too high.

- 200 LFM airflow, .5V diode voltage drop
- Temperatures are borderline

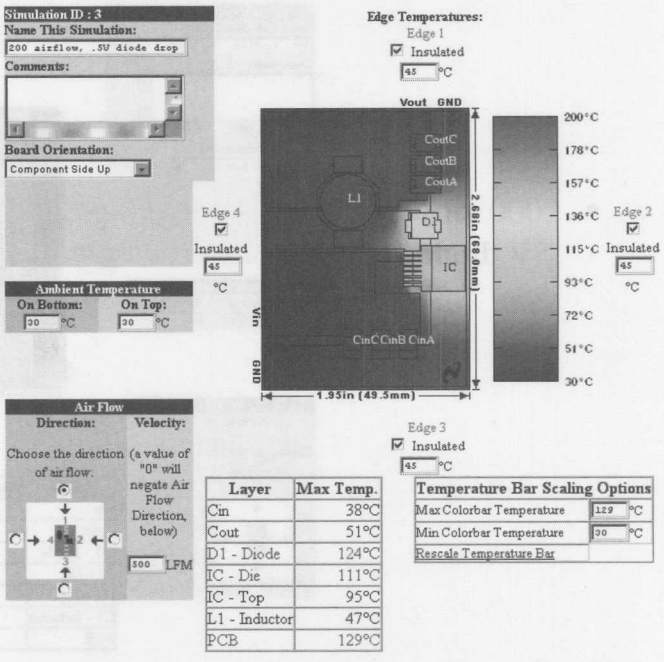


Layer	Max Temp.
Cin	44°C
Cout	61°C
D1 - Diode	143°C
IC - Die	130°C
IC - Top	115°C
L1 - Inductor	56°C
PCB	146°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	146 °C
Min Colorbar Temperature	32 °C
Rescale Temperature Bar	

With 200 LFM the temperatures are marginal.

- 500 airflow, .5V diode voltage drop

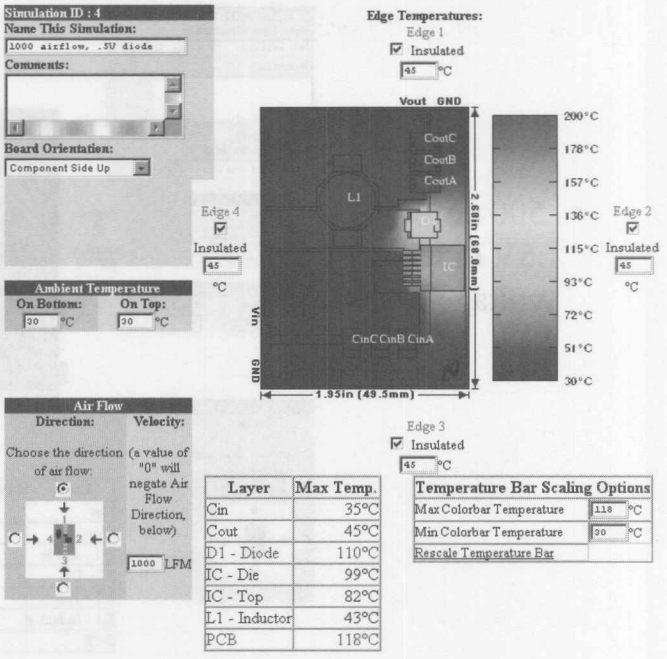


Layer	Max Temp.
Cin	38°C
Cout	51°C
D1 - Diode	124°C
IC - Die	111°C
IC - Top	95°C
L1 - Inductor	47°C
PCB	129°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	129 °C
Min Colorbar Temperature	30 °C
Rescale Temperature Bar	

With 500 LFM, the temperatures are now acceptable.

- 1000 airflow, .5V diode,

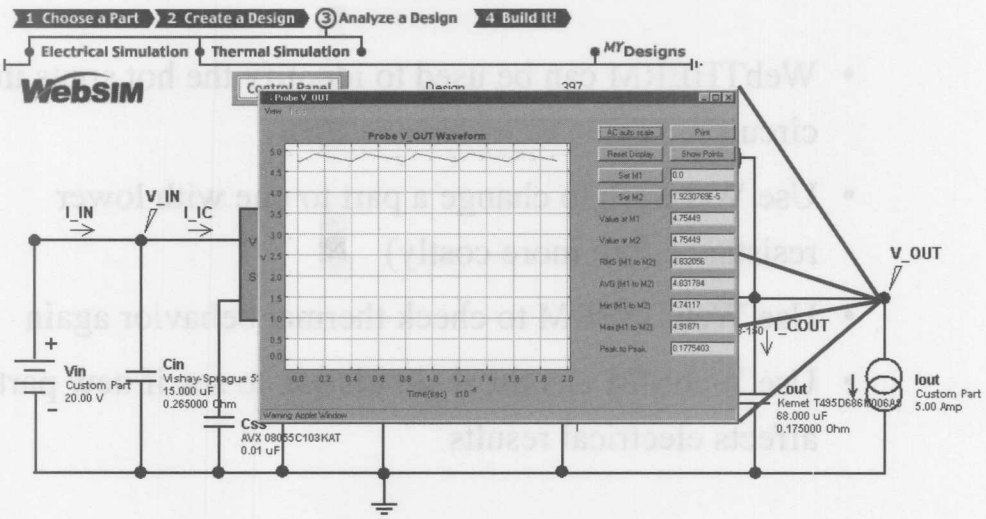


Layer	Max Temp.
Cin	35°C
Cout	45°C
D1 - Diode	110°C
IC - Die	99°C
IC - Top	82°C
L1 - Inductor	43°C
PCB	118°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	118 °C
Min Colorbar Temperature	30 °C
Rescale Temperature Bar	

Here are the results from the 1000 LFM air flow simulation for comparison. Temperatures are below 110°C.

Perform Electrical Simulation



Now we go back to WebSIM and perform an electrical simulation. The results are still acceptable.

New Part Fixes the Problem

- WebTHERM can be used to identify the hot spots in a circuit
- Use Webench to change a part to one with lower resistance (but more costly)
- Use WebTHERM to check thermal behavior again
- Use WebSIM electrical simulation to see if new part affects electrical results

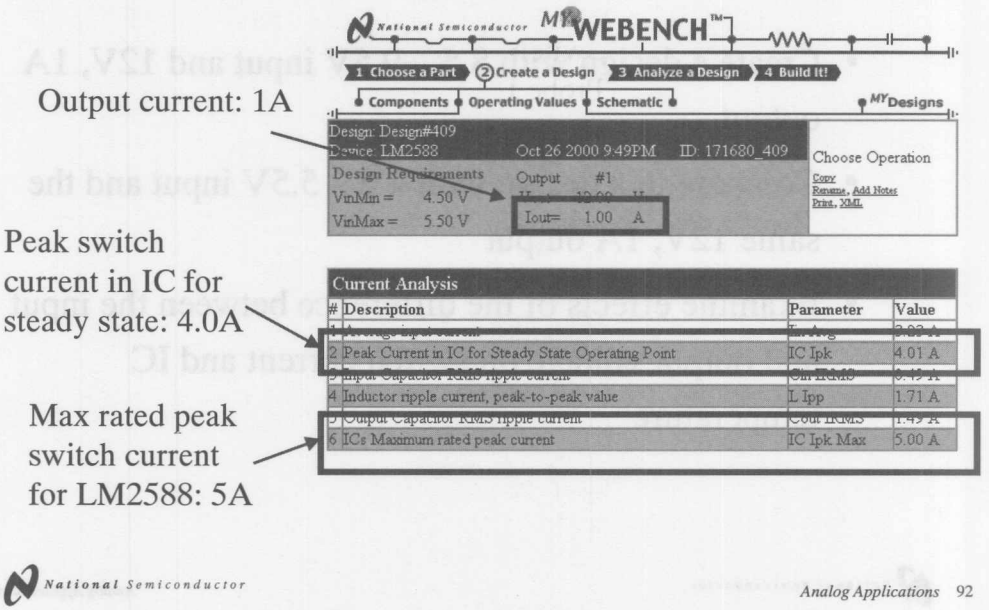
Using WEBENCH, we have identified a thermal problem, changed out a part and verified the new design using both the electrical and thermal simulators. Thus we see that WEBENCH offers an unprecedented level of on line design capability allowing the user to observe effects and interactions in both the schematic and physical layout regimes. This allows the user to identify problems up front before the prototype is built, and save a lot of time.

Example 2: Boost Topology

- Create a design with 8.5 – 9.5V input and 12V, 1A output
- Compare to a design with 4.5 – 5.5V input and the same 12V, 1A output
- Examine effects of the difference between the input and output voltage on switch current and IC temperature

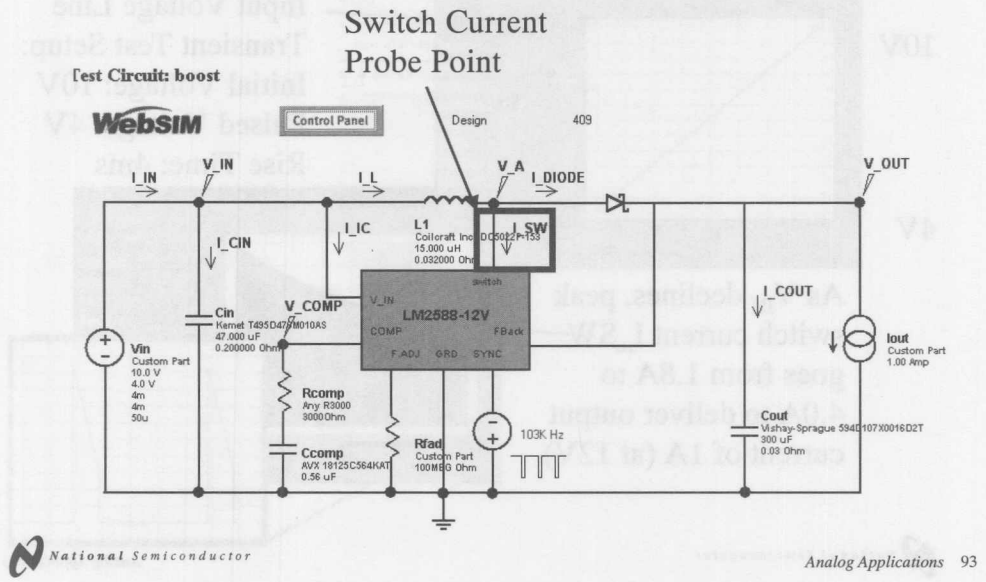
In the second example, we look at a boost topology. We choose 4.5 to 5.5V for the input voltage, and 12V with 1A for the output. Using WEBENCH we will observe the behavior of the switch current in the voltage regulator, which goes much higher than the 1A rating of the output. We will also compare the electrical and thermal characteristics of this design with a design using 8.5 to 9.5V for the input and the same 12V, 1A for the output.

5Và12V Boost Op Values



In the Create a Design step, we click on the Operating Values tab and we show the operating values for the design with 4.5 to 5.5V input voltage. At nominal operating conditions, the peak switch current is about 4A which is within the 5A spec of this part. This is quite high compared to the maximum output current for this design which is only 1A.

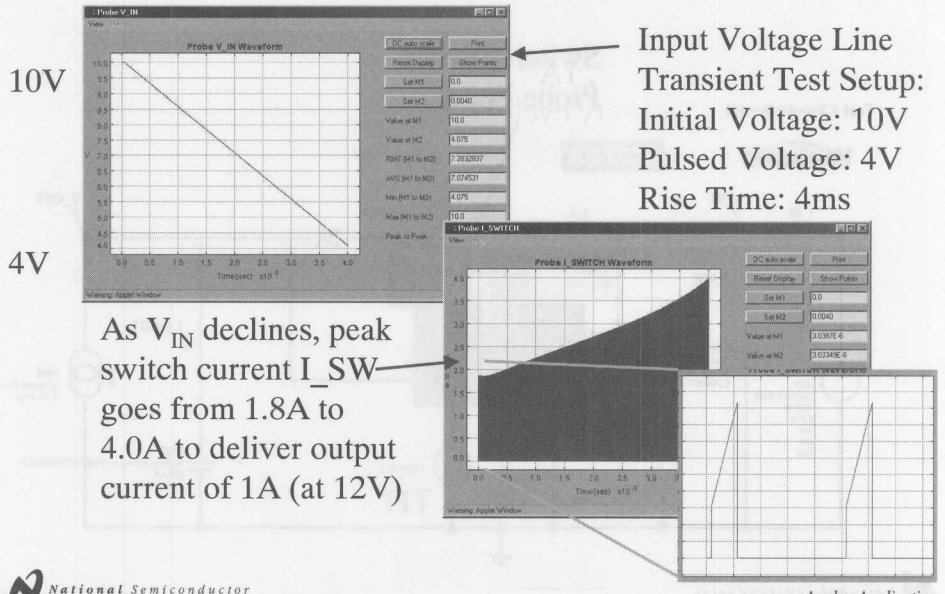
5Và12V Boost Schematic



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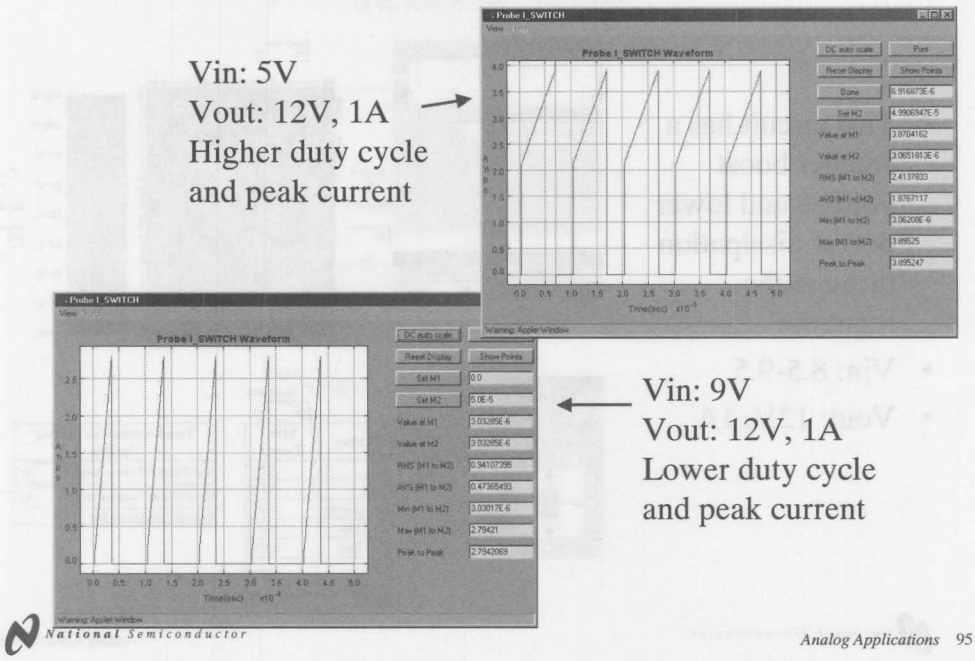
This is the schematic for the boost topology used in this design. Using WebSIM, we will be looking at the switch current at the I_SW probe in this simulation.

Switch Current Requirements for 12V Boost



We set up a line transient test in WebSIM where the input voltage is varied from 10V down to 4V over 4msec. The simulation waveforms show that although the output current is only 1A, the current on the switch in the regulator goes from 1.8A up to 4A as the input voltage drops. This is why the part must be rated for a higher switch current than the nominal output current.

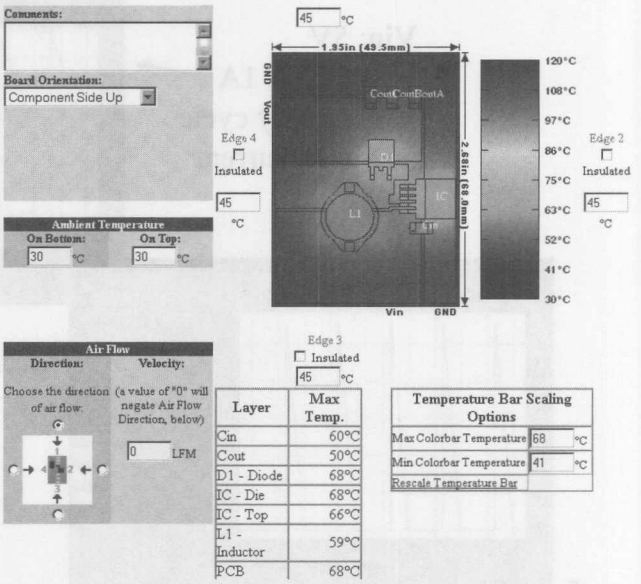
WebSIM Current Waveforms at IC



We zoom in on the I_SW waveforms to observe the switching behavior of the regulator under two extreme conditions. When the input voltage is 9V and the output voltage is 12V, the duty cycle and peak current are low, about 32% and 2.8A respectively. When the input voltage is set to 5V, further away from the output voltage, the duty cycle and peak current are much higher, about 65% and 3.9A respectively. Under these conditions, temperature may be a problem. So we use WebTHERM to examine the temperature behavior of this design.

WebTHERM Output

- This circuit has a smaller boost voltage and lower power dissipation through the regulator
- Vin: 8.5-9.5
- Vout: 12V, 1A



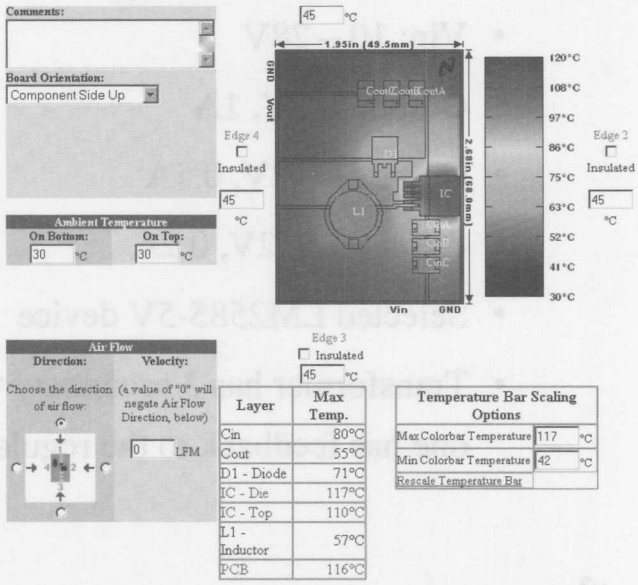
Layer	Max Temp.
Cin	60°C
Cout	50°C
D1 - Diode	68°C
IC - Die	68°C
IC - Top	66°C
L1 - Inductor	59°C
PCB	68°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	68 °C
Min Colorbar Temperature	41 °C
Rescale Temperature Bar	

Here we see the thermal behavior of the boost design with 8.5 to 9.5V input and 12V, 1A output. This simulation uses no fan with ambient temperature set to 30°C. The results show that all temperatures are below 70°C

WebTHERM Output

- This boost circuit has higher power dissipation through the voltage regulator than the diode
- Vin: 4.5-5.5
- Vout: 12V, 1A



Layer	Max Temp.
Cin	80°C
Cout	55°C
D1 - Diode	71°C
IC - Die	117°C
IC - Top	110°C
L1 - Inductor	57°C
PCB	116°C

Temperature Bar Scaling Options	
Max Colorbar Temperature	117 °C
Min Colorbar Temperature	42 °C
Rescale Temperature Bar	

This is the boost circuit with the input voltage range set to 4.5 to 5.5V and the output set to 12V and 1A. Temperatures are significantly higher than the previous design, with the IC die temperature at 117°C which is marginal. This makes sense given the higher duty cycle and higher current present in the voltage regulator compared to the previous design.

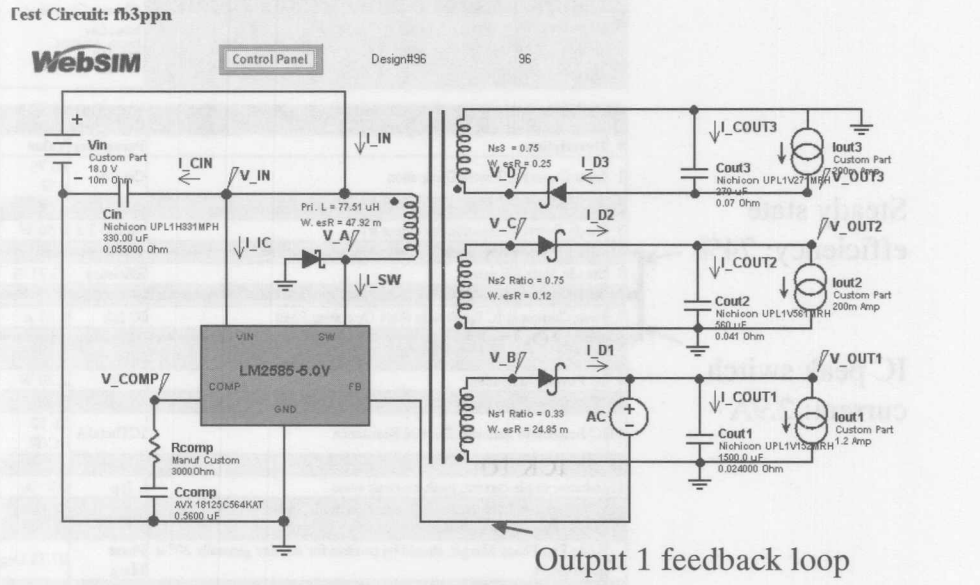
This is a good example of how one can use WEBENCH to observe the behaviors of a voltage regulator circuit and make sure that a design is robust under both operating and stress conditions.

3 Output Flyback Topology

- Vin: 10 – 28V
- Output 1: 5V, 1A
- Output 2: 12V, 0.5A
- Output 3: -12V, 0.2A
- Selected LM2585-5V device
- Transformer has 3 secondary windings, the first one has feedback to the regulator

This example shows one of the more subtle effects observed in a multiple output flyback topology.

3 Output Flyback



This is the schematic for a 3 output flyback topology. The feedback to the regulator comes from output number 1.

Flyback Operating Values

Design: Design#96							
Device: LM2585		Thu Jul 6 01:42:06 2000			ID: 171680_96		Choose Operation
Design Requirements		Output	#1	#2	#3		Delete, Copy Rename, Add Notes Print, XML
VinMin =	10.0 V	Vout=	5.0	12.0	-12.0	V	
VinMax =	28.0 V	Iout=	1.0	0.5	0.2	A	

Steady state efficiency: 74%

IC peak switch current: 2.9A

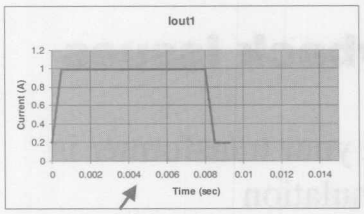
Operating Values			
#	Description	Parameter	Value
1	Input Capacitor Power Dissipation	Cin Pd	80.75 mW
2	Bode Plot Crossover Frequency, indication of bandwidth of supply	Cross Freq	1.14
3	Diode Power Dissipation for output #1	Diode1 Pd	0.50 W
4	Steady State PWM Duty Cycle, range limits from 0 to 100	Duty Cycle	64.81
5	Steady State Efficiency	Efficiency	73.71 %
6	Bode Plot Phase Margin (0°/20°) Frequency	Frequency	100.11
7	Peak Current in IC for Steady State Operating Point	IC Ipk	2.91 A
8	ICs Maximum rated peak current	IC Ipk Max	3.00
9	IC Power Dissipation	IC Pd	2.20 W
10	IC Junction Temperature	IC Tj	128.24
11	IC Junction to Ambient Thermal Resistance	ICThetaJA	26.52 øC/W
12	Average input current	Iin Avg	1.82
13	Inductor ripple current, peak-to-peak value	L Ipp	0.81 A
14	Continuous or Discontinuous Conduction mode, inductor current goes to zero in Discontinuous Conduction	Mode	Cont
15	Bode Plot Phase Margin, should be positive for stability generally 20° is good target	Phase Marg	87.38 Deg
16	Total Output Power	Pout	13.40
17	Peak-to-peak ripple voltage on Output number 1	Vout1 p-p	47.94 mV

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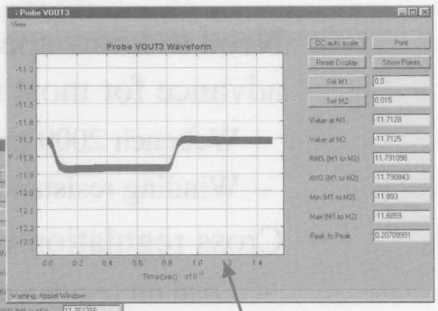
100

The operating values for the design look good

Load Transient Test

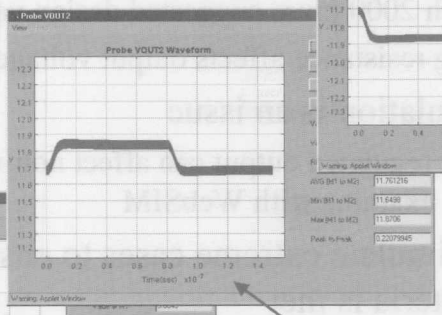


Iout 1: 200mA to 1A transient

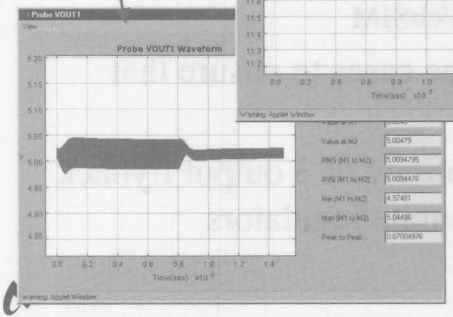


Vout3 varies from -11.98V to -11.82 V depending on Iout1

Good regulation for Vout1



Vout2 varies from 11.94V when Iout1 is at high current to 11.79 V when Iout1 is at low current



Here we have set up a load transient test where the load current on output 1 spikes from 200mA to 1A and back again.

Vout 1 has .07 peak to peak voltage ripple

Vout 2 has .223 peak to peak voltage ripple

Vout 3 has .21 peak to peak voltage ripple

When the current requirement goes up for output 1, the regulators duty cycle increases thereby increasing the voltage on the other outputs. Thus we see a certain amount of cross regulation between the regulated and unregulated outputs.

Multiple Output Flyback Issues

- Need to know specifics about your transformer in advance for most accurate simulation
 - Webench 2000 gives suggested design values
 - Winding resistance affects output voltage regulation
- Cross regulation is an issue
 - Load on regulated output can affect non-regulated outputs; examine with WebSIM
- Need to simulate extreme cases to ensure that design criteria is met
- Tradeoffs between simplicity of 3 output flyback vs performance of 3 separate regulators

We have used WEBENCH to examine the effect of cross regulation on a design using a flyback topology. WebSIM has allowed us to see if our design is robust enough to withstand our specified output transients before we construct a physical prototype. Thus, we can save time and avoid problems in the prototype phase.

Conclusions

- On line power supply design and simulation is powerful and easy to use
- WebSIM provides information about electrical behavior of circuit
- WebTHERM identifies temperature problems on the PC board
- WEBENCH shaves significant time off the design cycle
- Use POWER.NATIONAL.COM for your next design

In these examples we have shown that WEBENCH is a powerful tool for doing on line power supply design. The electrical behavior of the voltage regulator and accompanying circuit elements can be visualized realistic operating conditions using WebSIM. In a similar manner, thermal issues for the power supply design can be visualized in a printed circuit board layout. Using these tools, the designer can save time by uncovering problems at an early stage of the design process. We encourage you to try POWER.NATIONAL.COM for your next design.

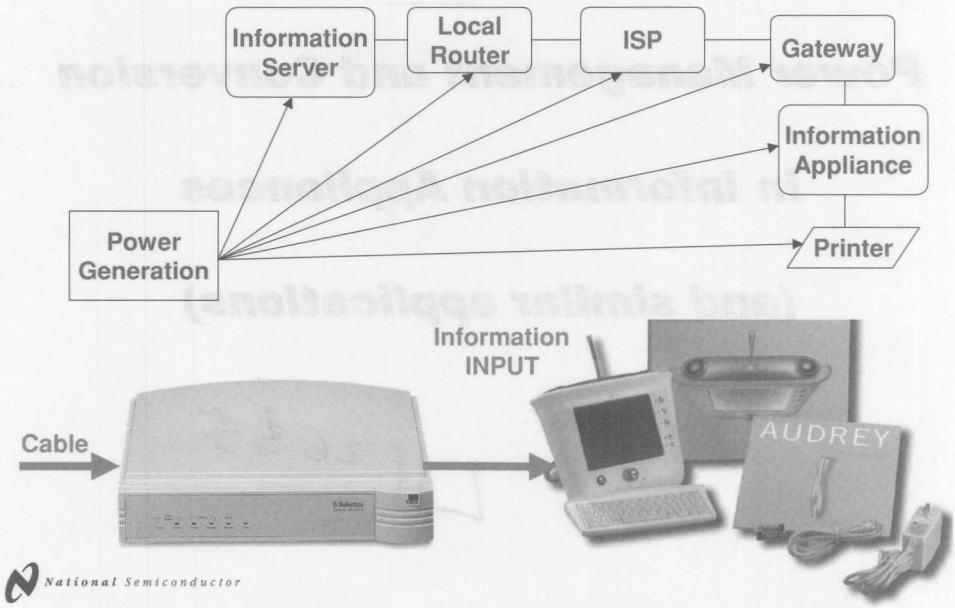
Power Management and Conversion

in Information Appliances

(and similar applications)

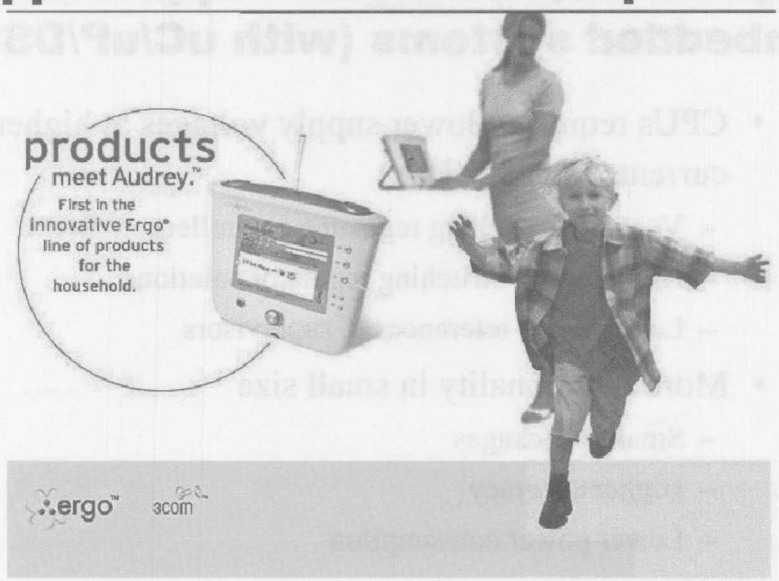
LM 2645

Power Required for all Information



Within information appliances, and the devices that interface with them, there are many requirements for power management. While each device has a source of power, most of the time that source must be converted to another voltage that is more suitable for running the device at its best performance.

There are 60 power management applications in this web experience



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Regulation of system voltages can be done using switching regulators of various sorts, or linear regulators. In addition, monitoring of system voltages is done using supervisory devices and/or voltage references. All these components are included in the broad term "power management."

In the example of the Audrey web appliance, there are 60 places power management devices are used (not counting MOSFET switches) to convert AC power to the system voltages required in the internet infrastructure, server, and client (web appliance). Often, the smaller systems require more supply voltages that optimize system performance and minimize power losses at the same time.

Key Trend: Proliferation of Internet appliances, information appliances, embedded systems (with uC/uP/DSP)

- CPUs requiring lower supply voltages at higher currents (e.g. 1V/30A)
 - Versatile switching regulator controllers
 - High-current switching regulator solutions
 - Low voltage references & supervisors
- More functionality in small size
 - Smaller packages
 - Higher accuracy
 - Lower power consumption

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Analog Applications 4

The key trend driving much of power management product development is the proliferation of systems that resemble computers. Internet appliances, information appliances (automotive and others), and embedded systems using microcontrollers, microprocessors, and DSP all use CPUs with particular power requirements. As desktop and notebook computers have a migration path to use CPUs operating at lower voltages and higher currents, the related systems follow suit. This produces requirements for low-voltage high-current switching regulators, often based on a versatile controller, and low-voltage references and supervisory devices.

System voltages are not only falling, they are proliferating. Where once 5V and 3.3V were sufficient, now 2.9V, 2.5V, 1.8V, 1.5V, and 1.25V may all be required in the same system. In addition, the systems continue to gain features while being constrained to the same (or smaller) physical size. This puts pressure on the power supply designer to provide power conversion with higher efficiency and smaller size, and often at higher accuracy. (The experienced designers will recognize that these goals are usually conflicting.)

In this portion of the seminar, we will be reviewing the latest power management products offered by National Semiconductor, then will study several examples of power conversion that meet the tough requirements of internet appliances (and related applications).

Power Management
New Product Update and New Solutions

- Update
 - References & Low Dropout Regulators
 - Supervisory & Current Sense
 - Switching Regulators & Controllers
 - Industry Standard Multiple-Sourced Low Dropout Reg.
- New Solutions
 - Power conversion in Information Appliances



Many new power management devices are now available. The following is an overview of those devices, including voltage references and low dropout regulators, supervisory and current sense products, and switching regulators and controllers.

In the discussion of new solutions, we will examine the use of several of the new switching controllers to address the needs of information appliances.

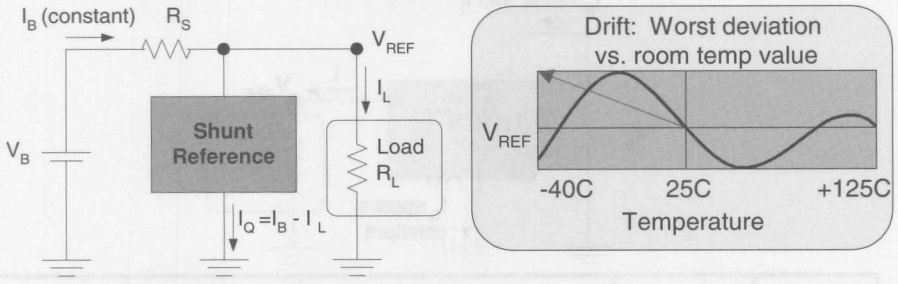
Popular industry standard low-dropout regulators have recently been introduced by National Semiconductor, such as the LM1117 which is a 800mA LDO and the LM1084, 1085, 1086 in 5A, 3A and 1.5A respectively.

Voltage References

- Series references (low-dropout)
 - LM4140 Low-drift, low noise
 - LM4130 High-accuracy
 - LM4120/21 Small package (SOT-23)
- Shunt references (current-fed)
 - LM4050/51 Small package (SSOT-23)
 - LM431 Tiny micro SMD package

National has a full line of voltage references. Now offering both series and shunt references, a variety of performance levels is available from general purpose to extremely high precision. In addition, many of the established references are now available in the new smaller packages, including LM4040 and LM4041 in SC-70.

New Shunt References



Device	Drift (best)	Accuracy (best)	Noise (typ, 10Hz ~ 10kHz)	Operating Current	Output Voltage
LM4050 LM4051	50ppm/°C	0.1%	41 μVrms	60 μA ~ 15mA	2.5 ~ 10V; Adj.
LM431 micro SMD	55ppm/°C*	2.2%		1mA ~ 100mA	2.495 (adj to 37V)

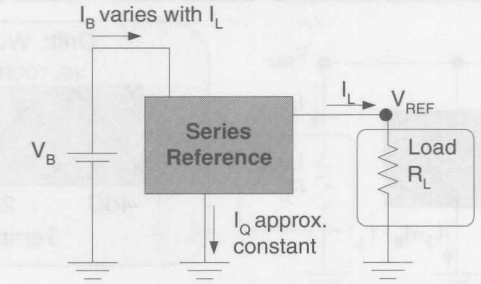
* maximum deviation over operating temperature range

A shunt reference operates like a zener. It produces an output voltage while consuming current. Because the available supply is normally of a constant voltage, if the load current varies, the current consumed by the reference must vary so that the sum of the two currents is the same. Many shunt references can operate with a very small supply current, but must accommodate a higher current in case the load goes away.

The LM4050 and LM4051 are good general-purpose references. The LM4050 is available in five standard voltages (2.5, 4.096, 5.0, 8.192, and 10V), while the LM4051 is adjustable from a minimum of 1.2V.

The venerable LM431 has been updated with a new, smaller package, the micro SMD. It is also available in 8-pin surface-mount, SOT23, and TO-92 packages. The drift of the LM431 is similar to that of the LM4050, although it is tested differently. The LM431 drift is measured as the maximum change in reference voltage over the maximum operating temperature range, -40°C to +125°C. The LM4050 and LM4051 are tested as precision references, checking the maximum deviation from the 25°C value to the highest and lowest operating temperatures.

New Series References



Device	Drift	Accuracy	Noise	Input Voltage	Output Voltages
LM4140	3ppm/°C	0.1%	2.2μVpp	1.8V~5.5V	1.024 ~ 4.096
LM4130	10ppm/°C	0.05%	125μVpp	Vo+0.275V ~ 6V	2.048 ~ 4.096
LM4120 LM4121	50ppm/°C	0.2%	20μVpp	Vo+0.21V ~ 14V	1.8V ~ 5.0V, Adj.

Series references operate much like low-dropout linear regulators. Powered by a system supply voltage, they draw an operating current that's not heavily dependent on the load current.

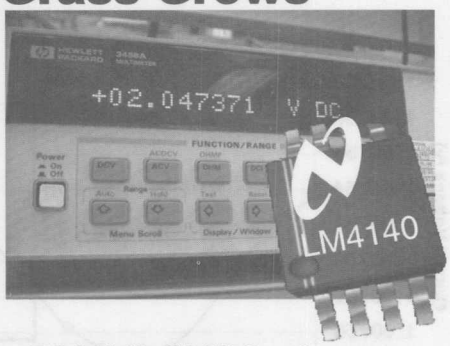
The LM4120 and LM4121 are general-purpose references, very similar in performance to the shunt references LM4050 and LM4051. They have good accuracy and low noise, and can operate with the input voltage only 210mV greater than the output voltage. The LM4120 and LM4121 are available in the small SOT23 package. Standard voltage options include 2.048 and 4.096 for data conversion, and 1.8, 2.5, 3.0, 3.3, and 5V for power supply applications.

Offering exceptional accuracy and low drift, the LM4130 is the world's first CMOS reference that uses EEPROM techniques to correct for curvature, temperature drift, and accuracy after packaging. Drawing less than 75uA supply current, the LM4130 can also source up to 30mA to the load. It is available in the 5-lead SOT23 package in three standard output voltages: 2.048, 2.5, and 4.096V. Check out the thermal hysteresis performance – it has only 10% of the hysteresis found in bipolar devices, or about 113uV from –40 to 125°C.

The highest-performance sub-bandgap reference on the market, the LM4140 has extremely low drift, very good accuracy, and excellent noise. Supply current is typically 230uA, and is reduced to less than 1uA in shutdown mode. Five standard output voltages are available: 1.024, 1.25, 2.048, 2.5, and 4.096V.

LM4140 Precision Reference Drifts Slower Than Grass Grows





4 inch blade of grass

- 2 inches/week
- 0.012in/hr
- 12,000 ppm/hour

LM4140 CMOS reference

- 0.02ppm/hr long term drift
- Measuring this drift is 600,000 times more boring than watching grass grow

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Analog Applications 9

Some people say watching the grass grow is boring.

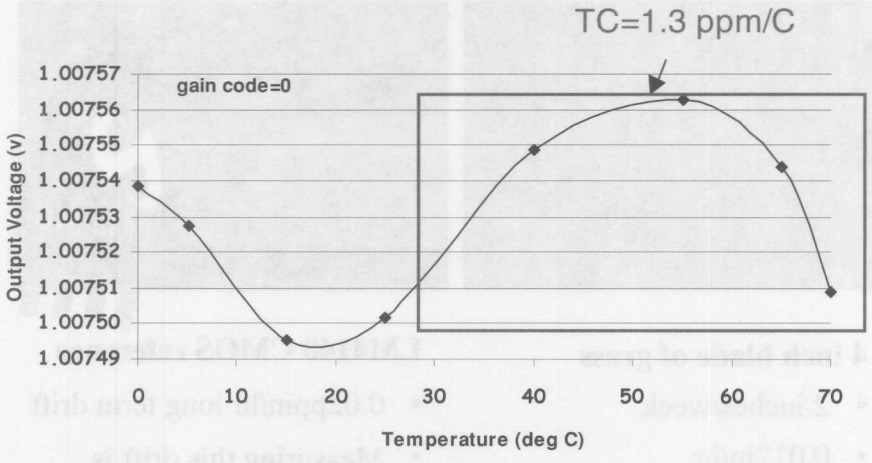
After all, a 4 inch blade of grass only changes 2 inches in a week, or 0.012in/hr (that's 12000ppm/hour).

The LM4140 CMOS reference has a long term drift of 0.02ppm/hr. Testing that drift is 600,000 times more boring than watching the grass grow.

Some people might even say, its more interesting to watch a stampede in a snail farm where it takes a few days to notice any changes.

But remember, any system is as accurate as its voltage references. National's new high precision micro power reference, LM4140, is among the very best..

LM4140 Tempco is Very Low, <1ppm/°C typ

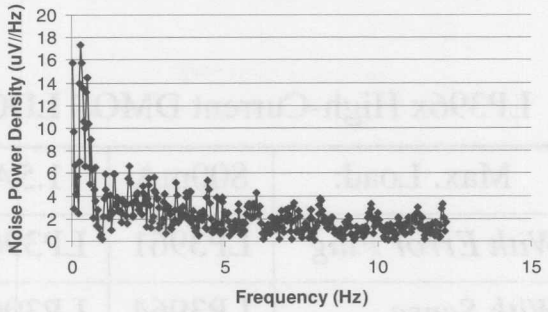


$$TC = Tempco = \frac{[(V_{OUT(70°C)} - V_{OUT(25°C)}) / V_{OUT\,(25°C)}] \times 10^6}{(70°C - 25°C)}$$

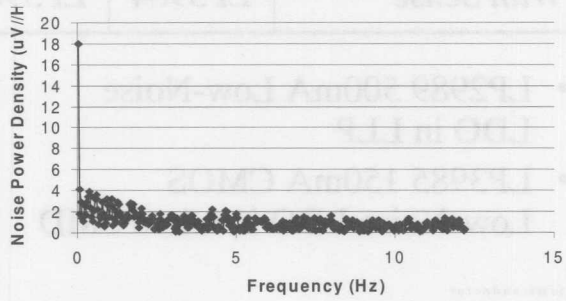
The high performance of the LM4140 is due to its multi-die design. The bipolar low-noise reference is combined with CMOS EEPROM and DAC trim in an 8-pin surface-mount package for the best of both worlds. The plot above shows the drift of a typical LM4140. While the limit for the highest grade device is 3ppm/°C, this particular 1.0V (custom output voltage) device has only 1.3ppm/°C drift.

LM4140 has Lower Noise vs competition

Competitive Precision Reference



LM4140



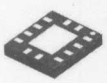
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Along with its super low drift and tight accuracy, the LM4140 has very low noise. Comparing the noise performance of an LM4140 reference to a competitive ADR190, the lab results show the LM4140 to be superior.

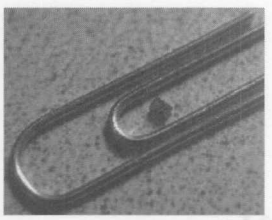
Low Dropout Regulators

- LP396x High-Current DMOS LDOs

Max. Load:	800mA	1.5A	3A
With Error Flag	LP3961	LP3962	LP3963
With Sense	LP3964	LP3965	LP3966



- LP2989 500mA Low-Noise LDO in LLP
- LP3985 150mA CMOS Low-Noise LDO in micro SMD



National Semiconductor

Analog Applications 12

While the series-type references could be used for low-dropout regulators, they have limited output current range, and their performance is optimized for use as a reference. Several new low-dropout regulators are now available, handling load currents of 150mA (for a low-noise portable application) up to 3A (for heavier loads in line-powered systems).

The LP396x family includes three current ranges and two sets of features. The Error Flag, available on the LP3961, LP3962, and LP3963, indicates when the output voltage is more than 10% below its nominal value. The Sense pin, available on the LP3964, LP3965, and LP3966, allows for more precise control of the output voltage, by sensing the feedback voltage directly at the load, rather than at the regulator output pin.

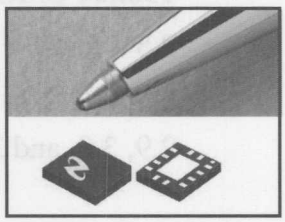
To handle the power dissipation due to load currents of 800mA to 3A, the LP396x are in TO-220 and TO-263 power packages. The 800mA and 1.5A devices are also in SOT-223.

To get the most power out of the 500mA low-noise LDO LP2989, it is now available in the leadless leadframe package, or LLP.

The smallest packaging now available is the micro SMD, used for the LP3985 150mA LDO. Originally designed for use in the cellular telephone handset, the LP3985 is equally appropriate in other portable systems requiring a low-noise supply voltage.

LP2989 Delivers 500mA in LLP

- LP2989 has low noise, precision
 - 18μVRMS noise with 0.01μF bypass
 - Stable with ceramic output capacitors
 - 0.75% tolerance (A grade)
- 8-pin Leadless Leadframe Package (LLP)
 - Only 4mm x 4mm x 0.8mm
 - Low thermal resistance, typ. 50°C/W with good thermal plane



National Semiconductor

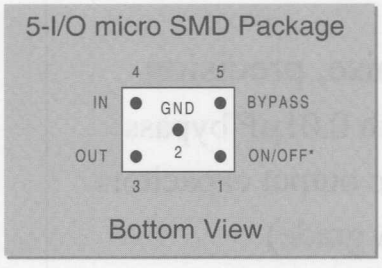
The LP2989 precision LDO offers a low noise precision output at up to 500mA load current. Using a 10nF bypass capacitor, the noise is held to a low 18uVrms (over the bandwidth 100Hz to 100kHz). The regulator is stable when used with ceramic output capacitors, with their very low effective series resistance (ESR).

The tolerance of the output voltage is 0.75% (A grade) at room temperature, and –4%/+2.5% (A grade) over the full –40°C to +125°C temperature range and up to the full 500mA load. This bipolar LDO has a low dropout voltage of less than 650mV over temperature at full load, falling to a low 1mV (typ) at 100uA load.

Shutdown control is provided on the LP2989, bringing supply current to less than 0.8uA, as is an error flag which detects when the output voltage is less than 5% of nominal.

In addition to excellent operation as a low dropout regulator, the LP2989 is now available in the new Leadless Leadframe Package (LLP). The 8-pin LLP is smaller and thinner than the 8-pin mini-surface-mount package, and has much better thermal resistance. With a good thermal plane, the 8-pin LLP package thermal resistance can reach 50°C/W, compared to 200°C/W for the mini-SO8 and 160°C/W for the standard SO-8. Additional information about the LLP package, including handling and soldering techniques, can be found in application note AN-1187, "Leadless Leadframe Package (LLP)".

LP3985, micro-LDO



- 150mA CMOS RF LDO
- 2.5V to 6.0V In
- 2.5, 2.6, 2.7, 2.8, 2.85, 2.9, 3.0, and 3.3V Out
- Stable with Ceramic Output Capacitors ≥1µF ± 25%
- 100mVmax Dropout at 150mA
- 30µVrms Typ Noise 10Hz-100kHz
- 60dB PSRR at 1kHz @3.1Vin
- ≤1µA I_Q when shut down
- Fast Turn-On

The LP3985 is the first of the family of micro-LDO products by Portable Power group at NSC specifically targeted for portable applications where size and weight are as important as the electrical performance. To maximize the operation time from battery, LP3985 performance is optimized with supply voltages all the way down to just above the output voltage + the dropout voltage of the LDO.

The micro-SMD package offers the minimum possible foot print, about half the size of a 1uF capacitor in 0805 foot print. In addition, the LP3985 requires only a very small 1uF ceramic capacitor on the output, and is stable with output capacitors up to 20uF and 5 - 500 mΩ ESR.

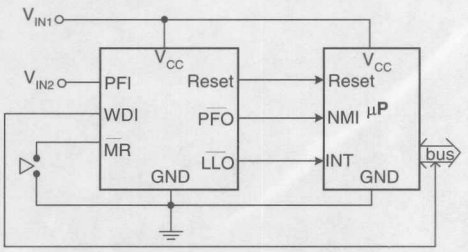
The LP3985's enhanced dynamic performance offers high Power Supply Rejection Ratio all the way down to the minimum operating input voltage.



The micro SMD package was chosen for the LP3985 because of the extreme high density required of circuitry within the wireless handset. This chip-scale package is currently the smallest form factor used for integrated circuits. The package is essentially the silicon IC chip with protective encapsulation on the backside, and solder bumps on the top of the die for connections. It uses standard SMT pick-and-place and soldering techniques. Details are found in application note AN-1112, "Micro SMD Wafer Level Chip Scale Package."

Additional information on working with the micro SMD package is available on the National web site, http://www.national.com/appinfo/microsmd.

LM37xx Power Supply Supervisors



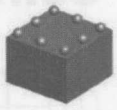
Product (Reset/$\overline{\text{Reset}}$)	Low Line Output	Manual Reset	Power Fail Flag	Watchdog
LM3700/LM3701	✓			
LM3702/LM3703	✓	✓		
LM3704/LM3705	✓	✓	✓	
LM3706/LM3707	✓			✓
LM3708/LM3709	✓	✓		✓
LM3710/LM3711	✓	✓	✓	✓

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Analog Applications 16

The recently introduced LM37xx power supply supervisors offer a broad line of features and combinations of features. Each combination is available as either normally high or normally low output. All have the low-line output, which detects when the supply voltage is lower than the pre-set threshold, and provides a delayed response when the supply voltage recovers. Other features include manual reset, for initiating a time-out sequence; power-fail flag; and watchdog input to monitor the operation of the microprocessor.

LM37xx Power Supply Supervisors



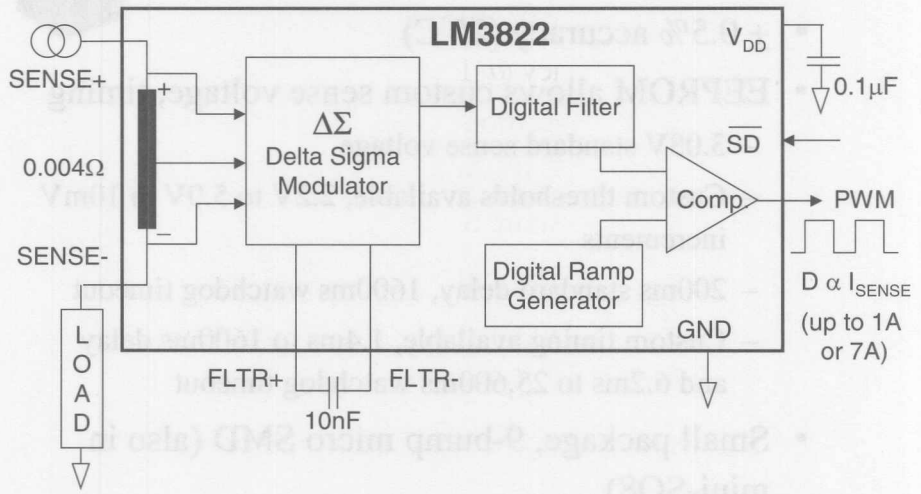
- ± 0.5% accuracy (25°C)
- EEPROM allows custom sense voltage, timing
 - 3.08V standard sense voltage
 - Custom thresholds available, 2.2V to 5.0V in 10mV increments
 - 200ms standard delay, 1600ms watchdog timeout
 - Custom timing available, 1.4ms to 1600ms delay and 6.2ms to 25,600ms watchdog timeout
- Small package, 9-bump micro SMD (also in mini-SO8)

The LM37xx power supply supervisors are based on a CMOS reference with tight accuracy. The reference voltage and the timing delay are programmed using EEPROM. The standard values are 3.08V sense voltage and 200ms delay, with 1600ms watchdog timeout. Other thresholds and timing are available upon request.

Supply current is typically 28uA, maximum 50uA.

To minimize the space required for the supervisory function, the LM37xx are provided in the 9-bump micro SMD package, as well as the 8-pin mini-surface-mount package.

LM3822 Current Sense Uses ΔΣ A/D Converter for Precision, Averaging



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Analog Applications 18

The LM3822 Current Gauge provides easy to use precision current measurement with virtually zero insertion loss. The internal 0.003Ω current sense resistor limits the voltage drop to 3mV.

The Delta Sigma analog to digital converter is incorporated to precisely measure the current and provide a current averaging function to reduce the measurement errors due to current spikes.

The duty cycle of the PWM output is proportional to the magnitude and direction of the current being sensed.

A duty cycle of 50% indicates zero current flow. If current is flowing in positive direction the duty cycle will be greater than 50%. Conversely, the duty cycle will be less than 50% for currents flowing in the negative direction.

LM3822 Precision Current Gauge Ideal for Battery Chargers

- Precision Low-Value Internal Sense Resistor
 - ± 2% Accuracy @ 1A
 - Ultra Low Insertion loss (0.003Ω typ)
 - Internal Current Sense Resistor
 - Low Temperature Sensitivity
- PWM output indicating Magnitude and Polarity
- Low Voltage Operation (2V to 5.5V)
- Low Quiescent Current (1.8 μA typ)
- Small MSOP-8 Package

All the features and performance of the LM3822 have been optimized for use in battery chargers. The typical application is for a cellular telephone, either in the handset or a cradle charger.

Switching Regulators

- Integrated Regulators
 - LM2612 Low-voltage High-efficiency buck
 - LM2698 **SIMPLE SWITCHER**™ boost
- Switching Controllers
 - LM2633 Two-Phase Notebook Triple Supply
 - LM2639/LM2720/LMS1145 3- or 4-Phase Notebook Supply
 - LM2645 Two-Phase Quad Supply
 - LM3477 High-side (step-down)
 - LM3478/88 Low-side (boost)

Among the recent introductions are a variety of new switching regulators and controllers. In the tradition of the SIMPLE SWITCHER converters, two of the regulators have on-board switches, and are highly integrated. The LM2612 is a buck regulator ideally suited to portable applications, while the LM2698 is a boost converter with a 1.25A/18V/0.2Ω switch. Its switching frequency is pin-selected to be 600kHz or 1.3MHz.

Because of the proliferation of CPU types and their applications (with unique power requirements), we have several new controllers intended for use on motherboards. They can also be used where high output currents at low voltage are required.

The LM2633 is a triple supply controller, with two out-of-phase switching outputs and one linear output. One output has VID control.

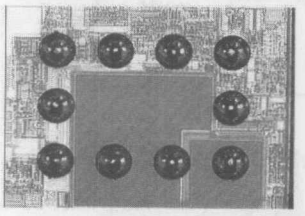
The LM2639 is a 3- or 4 phase controller optimized for use on a notebook motherboard. The LM2720 and LMS1145 are variations of the LM2639.

The LM2645 is a quad supply controller, with two out-of-phase switching outputs and two linear outputs.

The LM3477, LM3478, and LM3488 are versatile switching controllers that can be used in applications that are beyond the range of SIMPLE SWITCHER converters - whether lower voltage, lower output current, higher output current, or smaller size. We will see more of the switching controllers later in the presentation.

Subminiature Buck Regulator for Handheld Electronics: LM2612

- Low-Voltage Systems
 - Mobile Phones
 - Hand-Held Radios
 - Personal Digital Assistants
 - Hand-Held PCs
 - Portable Instruments



- Key Features
 - micro SMD package
 - Pin-selected output voltage, 1.05V, 1.3V, 1.5V, or 1.8V
 - Up to 400mA output
 - 2.8 ~ 5.5V Input
 - 600kHz, Sync to 1MHz

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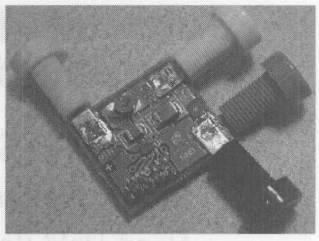
Analog Applications 21

The LM2612 is a specialized step-down switching regulator optimized for powering low-voltage circuits in handheld, portable electronic devices. Example applications include delivering up to 400mA at 1.5V to the DSP cores in cell phones, digital camera, and other devices powered by 1-cell Li-Ion and/or 3-cell NiMH batteries.

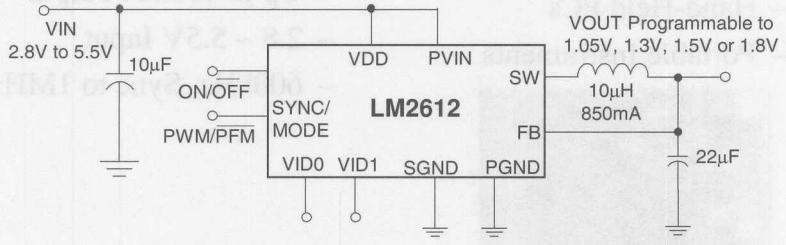
The LM2612 is housed in a 10-bump chipscale micro SMD package. It switches at 600kHz (internal oscillator), and using a patented circuit can synchronize from 500kHz to 1MHz when supplied with an external clock via its SYNC input.

Two pins, VID0 and VID1, select the output voltage from 1.05V to 1.8V. Use of VID control allows the output voltage to be changed dynamically, optimizing the balance of performance and efficiency in a system. In certain applications, external voltage divider resistors can be used to adjust the output voltage.

Micro SMD LM2612 Delivers 90% Efficiency at 150mA



- PWM or PFM modes
- Internally compensated
- Designed for ceramic output capacitors



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Analog Applications 22

Switching at such high frequencies allows the use of tiny, thin inductors and capacitors. The LM2612 is internally compensated eliminating two or three external components. The compensation scheme is tailored for using a ceramic chip capacitor in the output filter. Its output voltage is programmed digitally, eliminating two external feedback resistors. LM2612-based solutions, in fact, require only three tiny external components. All of these features combined make LM2612-based solutions literally one-third the size of the closest competing solution.

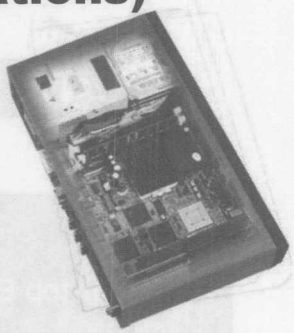
Internal synchronous rectification provides extremely high efficiency under heavy loads in PWM mode, and PFM mode extends high efficient operation to light load conditions. In PFM mode, the LM2612 consumes only 150uA (typ). The LM2612 regulator can be put into a low-power mode using the On/Off pin, where it will draw only 0.1uA (typ) of supply current.

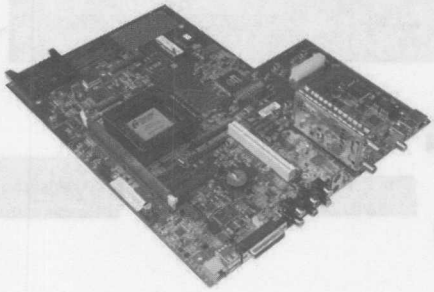
The LM2612 is National's first micro SMD switching regulator for hand-held portable systems. Key technology was invented, allowing for low quiescent power, high efficiency, minimum possible external components, and ease of use. These combine to make the LM2612 a perfect fit for single-cell lithium-ion or three-cell nickel systems where maximum performance and minimum solution size are both required.

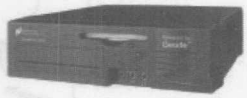
Like most of National's switching regulators, the LM2612 is available on a demo board for evaluation.

Power Conversion in Internet Appliances (and similar applications)

- Input supply typically via low-cost open frame AC/DC
- Output power up to 40W





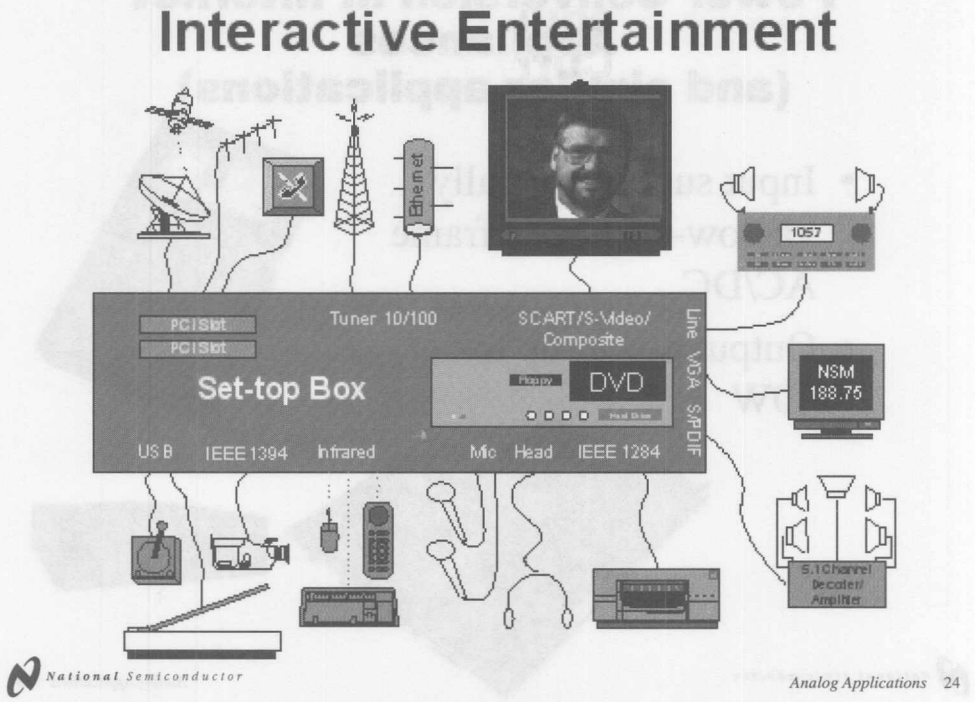


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Analog Applications 23

While it's helpful to understand the range of power management products now available, it is often more fun to explore design examples. The following part of the seminar will include a number of real examples of power supply system design. They are related (in varying degrees) to internet appliances, and the systems that connect to them. However, many of these applications are very similar to those found in instrumentation, production control, communications, etc. systems.

In general, the systems used in these examples are powered from a low-cost open frame AC/DC supply. This provides systems voltages at +12V and/or +5V. As we will see, most of the systems require several other voltages besides these, especially for the lower-voltage CPU, at load power from a few Watts to approx. 40W.



The prototype of the internet appliance, the set-top box is a controller for the user's video system. It links inputs such as digital satellite dish, ethernet, and DVD movies to outputs such as a video display. In the set-top box are a microprocessor, graphics system, interface devices, audio drivers, etc. – in other words, a highly specialized computer. Because this is a consumer system, low cost is important. In addition, the consumer expects increasing functionality in decreasing box size (or at least not increasing size), and a fan is prohibited. This puts constraints on the power converters to be very high efficiency

Set-Top Box Requirements Include Two High-Current Outputs

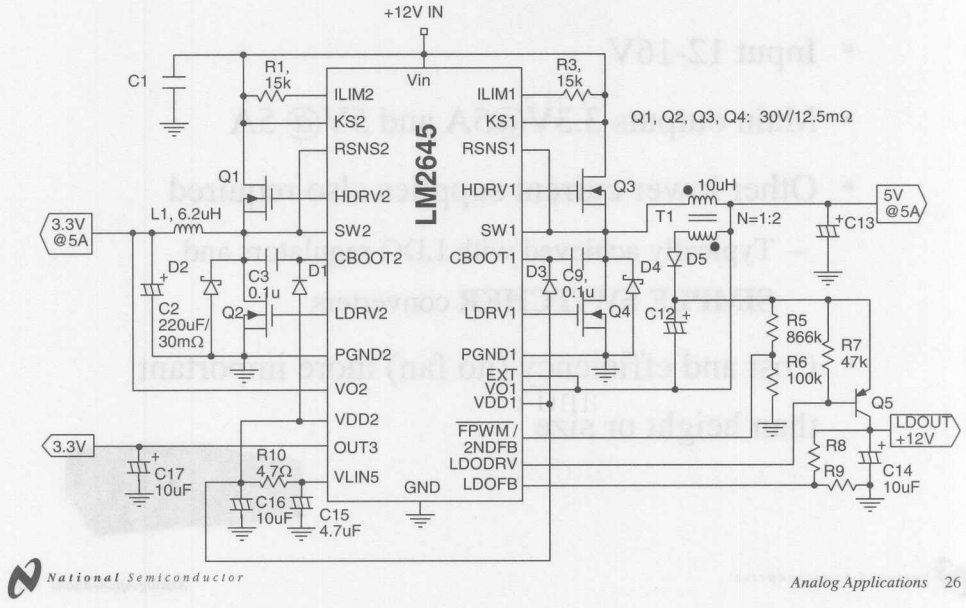
- Input 12-16V
- Main outputs 3.3V@5A and 5V@ 5A
- Other lower current supplies also required
 - Typically achieved with LDO regulators and **SIMPLE SWITCHER** converters
- Cost and efficiency (no fan) more important than height or size



Depending on the manufacturer, typically 5 or 6 supply voltages are required to be delivered from the 12-16V source. The most difficult are the high current 3.3V and 5V voltages, especially when low cost and high efficiency are required.

Other lower current supply voltages are usually required as well. These are typically achieved using SIMPLE SWITCHER DC/DC converters and LDO or quasi-LDO linear regulators.

Set-Top Box Power Supply



A quad controller, LM2645, can be used to provide both high-current output voltage, plus two low-power voltages.

As the LM2645 is a controller, both switching regulators have external FETs driven in a synchronous fashion for high-efficiency power conversion. By adding a winding to the 5V inductor, the LM2645 provides a low-current linear-regulated 12V supply. In addition, a 3.3V standby supply is available from the LM2645. Note that the current sense is being accomplished by sensing the voltage drop across the FET on-resistance.

In the drawing above, only the power stages are shown. The Power Good, Shutdown (each output and whole IC), and undervoltage delay controls are added to the more detailed circuit, as are the R-C compensation and capacitor-set soft start. Additional information about the LM2645 (and other devices described in this material) can be found in the device datasheet on our web site.

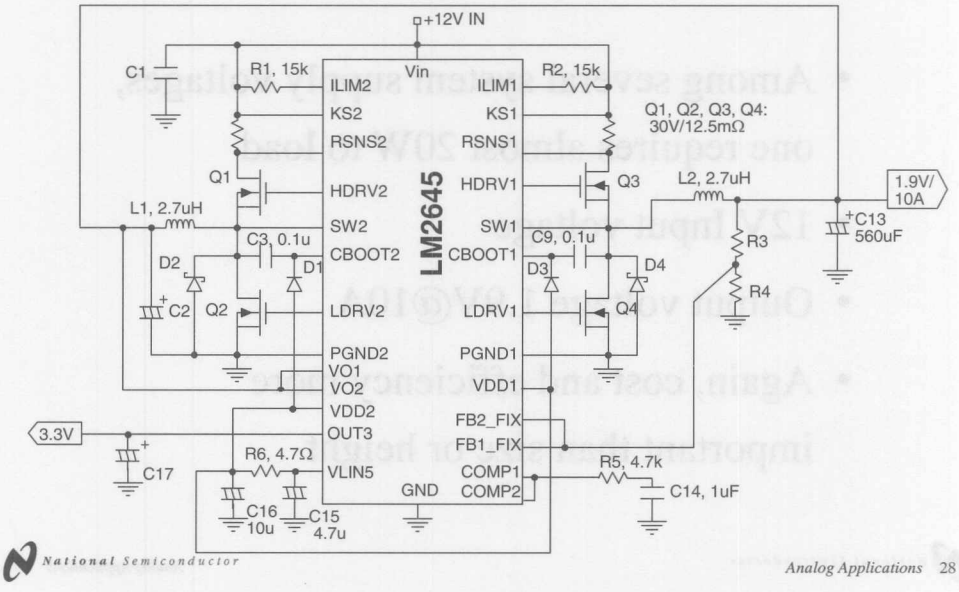
Game Appliance Requires 40W Output

- Among several system supply voltages, one requires almost 20W to load
- 12V Input voltage
- Output voltage 1.9V@10A
- Again, cost and efficiency more important than size or height

A game appliance is very much like a special-purpose computer. Because, like the set-top box, the game appliance is a consumer item, cost must be kept low. For this reason, the CPU is often a custom device, but related to standard state-of-the art CPUs. In the example we will consider, the CPU (and other load) requires a 1.9V supply on the motherboard rated for fairly high current, 10A.

Fortunately, the load transient requirements are not as stringent as for other similar circuits such as a notebook PC motherboard. This means standard design techniques are used for the output capacitor, rather than having to use special super-low-ESR capacitors.

Game Appliance Power Supply



Again, the LM2645 quad controller can be used to provide the CPU voltage. In this case, the two switching outputs are paralleled to combine their power capability. The feedback voltage goes to both switching controllers. With the two-phase operation of the LM2645, each regulator alternates delivering energy to the load. In this example, current sensing uses a current sense resistor to ensure good load sharing.

So that both regulators are enabled and start at the same time, ON1 and ON2 (the enable pins) are tied together, and the two softstart pins are tied together. (Not shown in the figure above.)

LM2645 - Two-Phase Synchronous Quadruple Regulator Controller

- Two synchronous buck controllers
 - 180° out of phase to reduce input RMS current
 - Output range 1.3V~5.5V
 - Current mode control
- Input Range 4.5V~30V
- Linear regulator controller
 - External PNP pass device
 - Output range 3.5V~15V
 - 3.3V/50mA and 5V reference outputs

The LM2645 is a good choice for a consumer application because of its two-phase operation. This minimizes the input capacitor RMS current, and allows for a smaller input capacitor than would otherwise be required. With current mode control, the loop compensation is simplified, and switch current is automatically limited in a cycle-by-cycle fashion.

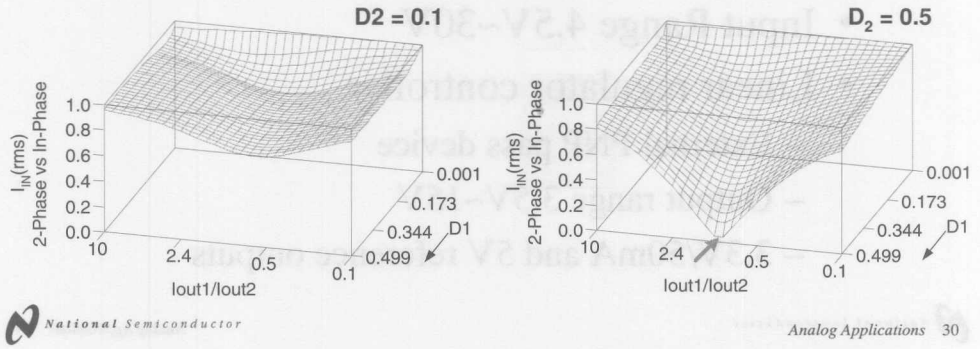
Both switching controller output voltages are controlled via analog feedback (resistor divider network) to be between 1.3V and 5.5V. The input voltage range is very wide, from 4.5V to 30V.

The linear regulator controller is designed to drive an external PNP pass device, with an output voltage of 3.5V to 15V. Output current is limited by the allowed power dissipation of the PNP transistor ($P_D = (V_{IN}-V_{OUT}) \times I_{OUT}$). Two other linear outputs are available, a 3.3V/50mA auxiliary supply and a 5V reference output.

For a similar two-phase synchronous switching controller with VID control of V_{OUT1}, see the LM2633.

2-Phase Operation Offers Cost Benefits

- Longer C_{IN} life
- Smaller C_{IN} needed
- Improves system efficiency
- Best benefit at D1=D2=50%, Iout1=Iout2



The fact that the two switching channels of the LM2633 are 180° out of phase will help reduce the RMS value of the ripple current seen by the input capacitors. That will help extend input capacitor life span and result in a more efficient system. In a mobile CPU application, both the CPU core and GTL bus voltages are rather low compared to the input voltage. The corresponding duty cycles are therefore less than 50%, which means there will be no over-lapping between the two channels' input current pulses. The equation for calculating the maximum total input ripple RMS current is therefore:

$$I_{IRMS} = SQRT[I_1^2D_1(1-D_1)+I_2^2D_2(1-D_2)-2I_1I_2D_1D_2]$$

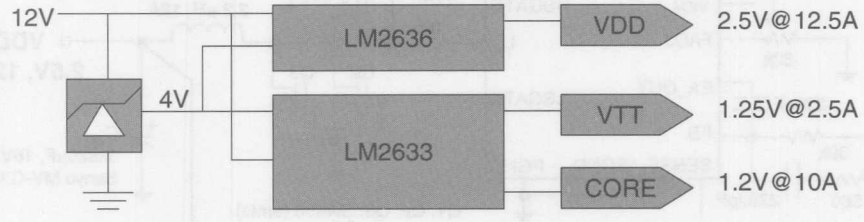
where I_1 is maximum load current of Channel 1, I_2 is the maximum load current of Channel 2, D_1 is the duty cycle of Channel 1, and D_2 is the duty cycle of Channel 2.

As an example, if Iload_max_1 = 6.8A, Iload_max_2 = 2A, D_1 = 0.09, and D_2 = 0.1, then I_{IRMS}=1.97A. We should choose input capacitors that can handle 1.97A ripple RMS current at highest ambient temperature. Comparison: If the two channels are operating in phase, the ripple RMS value would be 2.52A.

The graphs above show how the reduction of input ripple RMS current brought by the 2-phase operation varies with load current ratio and duty cycles. From the plots, it can be seen that the benefit of the 2-phase operation tends to maximize when the two load currents are equal. In fact, the absolute optimal operating point in terms of input ripple is at D1 = D2 = 0.5 and Iload_max_1 = Iload_max_2, when the input ripple current is zero for 2-phase operation.

DDR Memory Supply

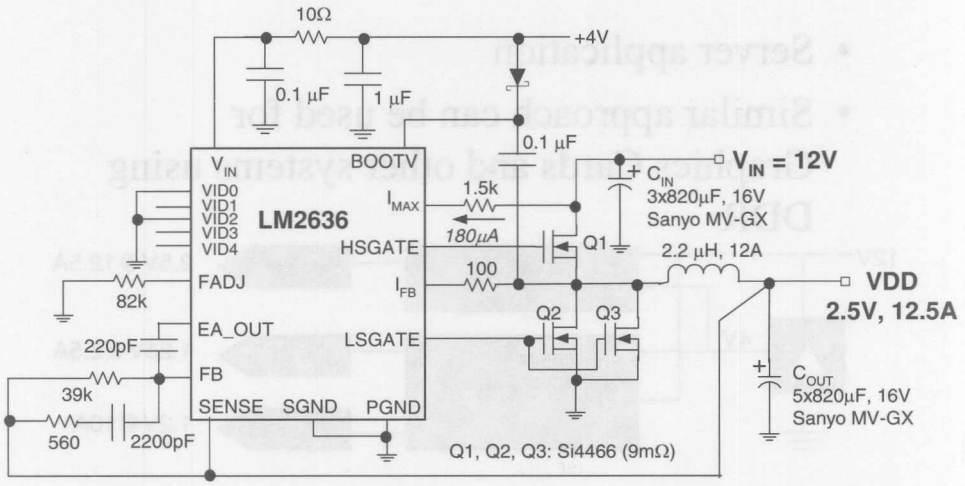
- Server application
- Similar approach can be used for Graphics Cards and other systems using DDR



DDR (Dynamic Data Refresh) memory is becoming a widely accepted form of memory in systems that must transfer data at high rate. Examples of this are in a server or a graphics card. DDR is built to operate from a supply voltage V_{DD} of 2.5V, and must have a termination voltage V_{TT} of exactly half that, or 1.25V.

In addition, the system usually requires a core voltage that can be provided along with V_{DD} and V_{TT}. An approach that works well and is cost-effective is to use a combination of switching controllers, such as the LM2636 and LM2633.

LM2636 Provides DDR Memory V_{DD}



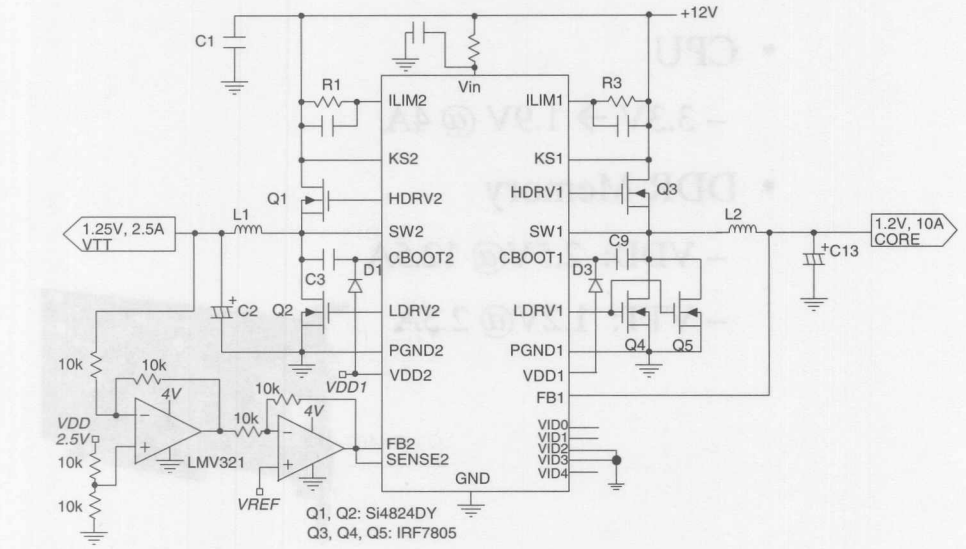
From the available source of 12V, the LM2636 can be used to deliver the VDD supply at 2.5V. The synchronous rectification output stage is constructed of one high-side MOSFET and two paralleled low-side MOSFETs. Because the duty cycle is low (roughly 2.5/12, or 20%), the low-side FETs are on a greater proportion of the time. To minimize their contribution to power losses, it's more important to have lower on-resistance on the low-side FETs.

The output voltage is set using the VID control on the LM2636. By grounding VID0 and VID2, and leaving the other pins open, the output voltage is set to 2.5V. The full control range of the LM2636 is 1.3V to 3.5V.

The current limit of the LM2636 is set by the resistor on the IMAX pin and the on-resistance of the high-side FET Q1. With the 9 mohm resistance of the Si4466, the peak switch current is set to:

$I_{PK} = 180uA * R_{MAX}/R_{ds(ON)} = 30A$

LM2633 Provides VTT, System Core Voltage



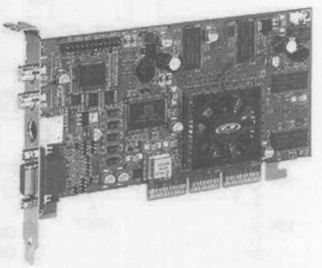
Like the LM2643, the LM2633 has two-phase synchronous switching regulators that can be used to deliver two output voltages. (It also has a linear regulator output, which is not being used in this example.)

Regulator 1 (right side of drawing) is delivering 1.2V at up to 10A to the system core. The voltage is controlled with the five VID pins. Grounding pins VID2 and VID3, while leaving the other three open, sets the output voltage to 1.2V. A total of three IRF7805 MOSFETs are used in the output stage of Regulator 1. They have a low 11mΩ on-resistance, and are fast-switching with low gate charge. Two FETs are paralleled for the lower part of the switch, to give even lower switch resistance. This keeps the efficiency high, as the bottom switch is on for a longer time than the upper switch (the duty cycle is low), and could otherwise dominate the system power losses.

The VTT output of Regulator 2 is being controlled through the LMV321 op amp to provide a voltage exactly one-half of the 2.5V VDD voltage (developed in the previous circuit). Because the output current is only 2.5A, the use of the asymmetric fast-switching dual Si4824DY is a good choice. Q1 has an on-resistance of 40mΩ, and Q2 is an even lower 17.5mΩ.

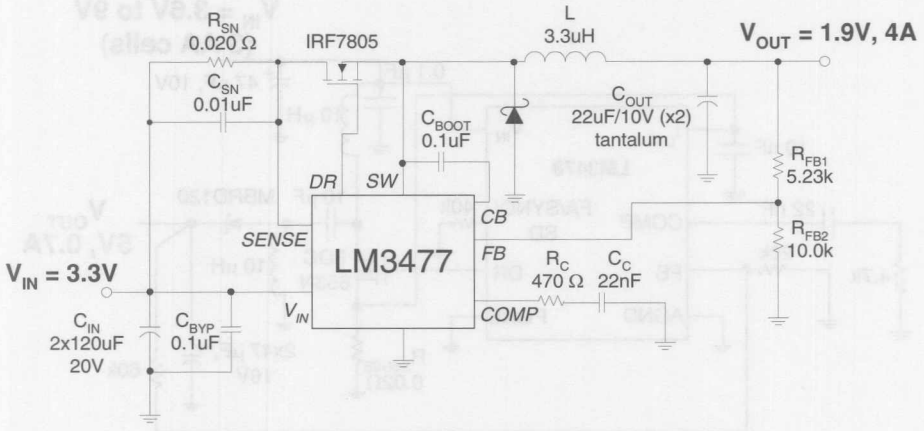
Graphics Card Supplies

- CPU
 - 3.3V → 1.9V @ 4A
- DDR Memory
 - VDD: 2.5V@ 12.5A
 - VTT: 1.2V@ 2.5A



Double data rate (DDR) memory is used in servers, computer-like appliances, and graphics cards for extra high-speed data transfer. Unlike the previous standard, SDRAM, DDR cannot operate from 3.3V, but requires a 2.5V supply It also requires a termination voltage of 1.2V. Another next-generation memory, RDRAM, requires the same 2.5V supply voltage as DDR.

Step-Down 3.3V to 1.9V @4A



The core processor in the graphics card of this example required a 1.9V supply at up to 4A load. To optimize the supply for size, performance, and cost, the LM3477 low-side controller was used in a buck (step-down) regulator configuration.

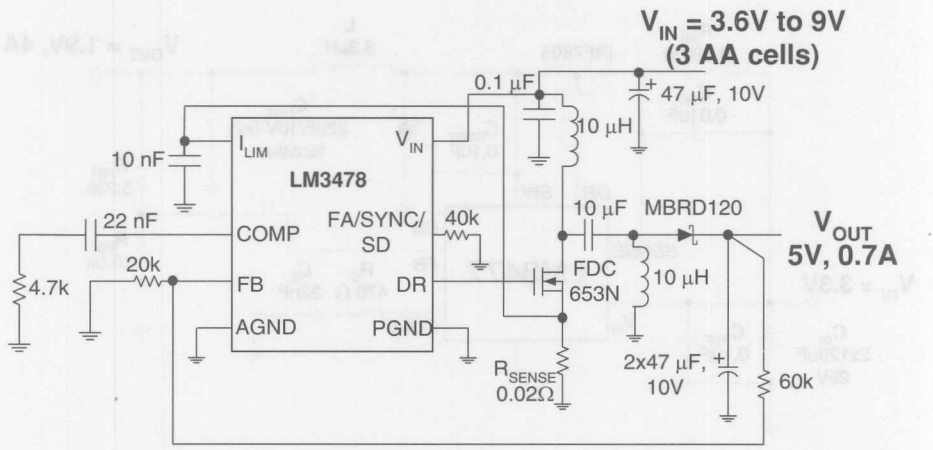
Key components in the design are the inductor, a 3.3uF surface-mount device from Coilcraft (D03316P-332); the diode, a Schottky (MBRD835L); the MOSFET switch, an IRF7805 with 11 mΩ on-resistance; and the output capacitor, two paralleled tantalum 22uF/10V capacitors.

The output voltage is set to 1.9V using the feedback resistors and the LM3477's internal 1.265V reference: $R_{FB1} = R_{FB2} \times (V_{OUT} - 1.265)/1.265$.

The input capacitor was carefully selected to be greater than 150uF, to avoid impedance interactions with input source. C_{IN} must also have RMS current capability for 2A (1/2 of max load).

As the LM3477 is a current mode device, an external sense resistor detects the switch current for use in the regulator control. In this application, the peak switch current at nominal 4A load will be approx. 4.5A. A 20mohm sense resistor was chosen, providing a maximum operating switch current of 100mV/20mohm=5A, and a 2nd level current limit at 350mV/20mohm=17.5A.

Digital Camera has Wide Input Range, Needs Regulated 5V Output

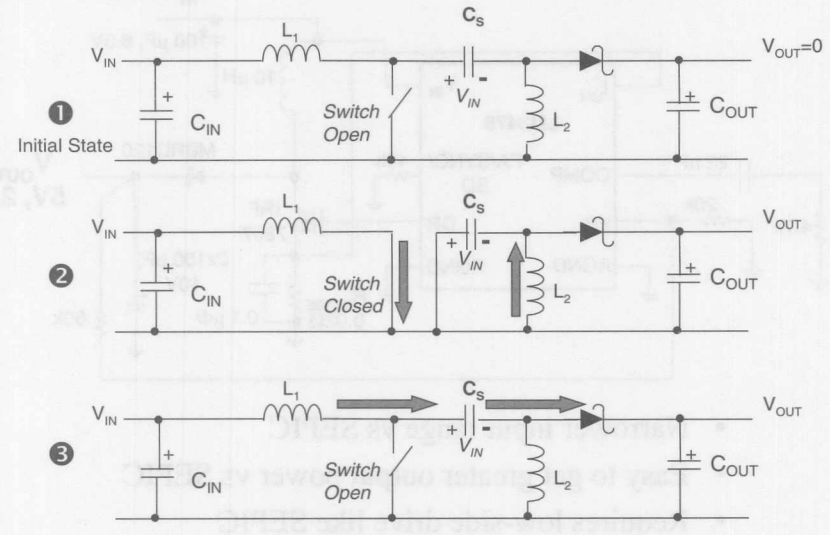


The circuit providing the power supply for a digital camera is a SEPIC (Single Ended Primary Inductance Converter) design. The most important advantage of the SEPIC is that it allows the input to go above and below the output voltage and still maintain regulation without requiring a transformer. This is key in this application, as the input voltage range (3.6 to 9V) includes the desired output voltage. The alternative would be a flyback design, which typically uses a more costly transformer instead of the two off-the-shelf inductors.

The output voltage is fed back to the LM3478 through the 60k/20k resistor divider. The control circuitry of the IC will adjust the on time of the FET as needed to hold the voltage at the FB pin at 1.23V.

SEPIC converters are known for being difficult to stabilize. Use of the LM3478 makes this easier. Because it operates as a current-mode controller, it has a simpler frequency response than a voltage-mode controller (thus it's easier to make stable). In addition, the switching frequency can be adjusted up to 1MHz, to optimize the stability using a given inductor and output capacitor.

SEPIC Transfers Energy Between C_S and L2 for Buck-Boost Function



1. The initial state of a SEPIC before the switch closes is shown above. The SEPIC capacitor C_S has charged to V_{IN}. The output is 0V, and no current is flowing in any of the components.

2. When the switch closes, V_{IN} is applied across the inductor L1. Current ramps up through L1, which stores energy (just like in a boost converter).

V_{IN} is also applied across L2! This voltage comes from the SEPIC capacitor. The SEPIC capacitor starts dumping its energy into L2 by ramping current through L2. The diode is reverse biased during this time.

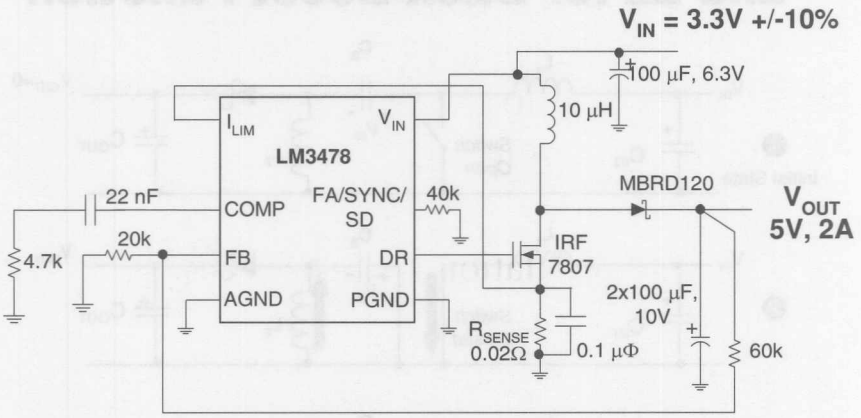
Now current is flowing in both inductors, and it can not change instantaneously when the switch opens again – it must continue flowing in the same direction.

3. The switch opens. Current through L1 has no place to go but through the SEPIC capacitor to the output capacitor and the output. The current through L2 must also go to the output.

In order for the current to continue to flow through L1, the voltage on the switch "boosts" up to $V_{IN}+V_{OUT}+V_{DIODE}$. The current flowing through the SEPIC capacitor charges it up again to enable it to transfer this energy to L2 when the switch closes.

There is an energy balance between the SEPIC capacitor and L2, which helps determine the value of the SEPIC capacitor. Keeping the value of the SEPIC capacitor low helps ensure stable operation.

3.3V to 5V Boost for I/O Card



- Narrower input range vs SEPIC
- Easy to get greater output power vs SEPIC
- Requires low-side drive like SEPIC

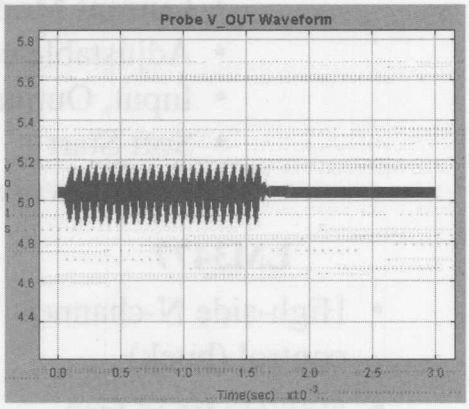
In many systems, a 3.3V supply is provided, yet some circuitry requires 5V. The wide input voltage range of the SEPIC is not an advantage, but a better solution is a simple boost converter. Like the SEPIC, the boost requires a low-side driver, so the LM3478 controller is a good fit.

The LM3478 is set to operate at the nominal switching frequency of 400 kHz, with the 40k resistor from the FA pin.

In this example, the load requires 5V at up to 2A, so the switch must be rated for at least 6A peak (the load current divided by duty cycle, plus inductor ripple current). The IRF7807, with its on-resistance of only 25mΩ, will have a voltage drop of 150mV with that peak current.

3.3V to 5V Boost Performance

- Use WebSIM to anticipate circuit behavior
- Test load regulation, line regulation, frequency response, steady-state



Load regulation: 0.3A to 2A to 0.3A

The LM3478 Boost converter is supported in the online tool set of Webench. For evaluation of the electrical behavior, we can use WebSIM, a power supply circuit simulator. After adjusting the component values to match those of our circuit, we can test load regulation, line regulation, frequency response, and/or steady-state operation.

As an example, we tested the regulator for load regulation, checking the output voltage as the load changed from 300mA to 2A and back to 300mA. The change is very smooth, although there is noticeably more ripple at the 2A load current. In fact, the regulator is on the edge of current limit at that point, although it is still maintaining regulation.

This preliminary check of the regulator can give us additional confidence that the bench testing will go well.

LM3477, LM3478 Details

Common Features

- Current Mode operation
- Adjustable current limit
- Input, Output Protection (UVLO, OVP)
- Soft Start
- Low-power shutdown (typ. 5uA)

LM3477

- High-side N-channel control (buck)
- 500kHz fixed freq.
- Wide input range, 2.95V ~ 35V

LM3478

- Low-side N-channel control (boost, SEPIC)
- 100kHz~1MHz adj.
- Wide input range, 2.95V~40V

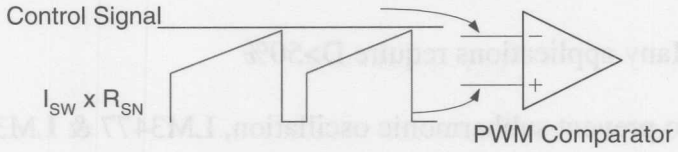
The versatile switching controllers LM3477 and LM3478 are variations of a common fundamental design. The protection and control methods are the same, but the driver outputs are different. LM3477 has a high-side driver, which can be used for buck (step-down) regulators. The LM3478 has a low-side driver, which is ideal for use in boost and SEPIC designs. The drivers are intended to work with N-channel enhancement-mode MOSFETs, so the LM3477 includes a bootstrap voltage pin.

Switching frequency is fairly high, to allow the use of smaller external components. The LM3477 is fixed at 500kHz, while the LM3478 is adjustable from 100kHz up to 1MHz.

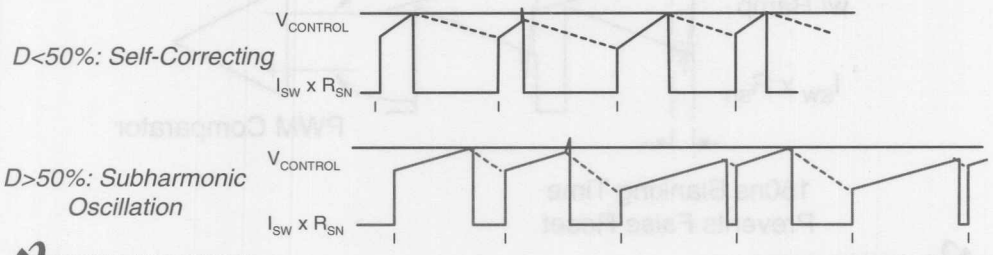
Both devices work over a very wide input voltage range, 2.95V up to 35 or 40V. This makes them suitable for use in some battery-powered applications, as well as line-powered and some automotive applications.

Also available is the LM3488, an upgrade of LM3478. In addition to the features of the LM3478, the LM3488 has the ability to synchronize the switching frequency to an external source, and has tighter tolerances on switching frequency, OVP thresholds, and output voltage.

Current Mode Control



- Provides cycle-by-cycle current limit
- Simplifies control loop (1 pole vs 2 pole)
- Requires D<50% for stable regulation



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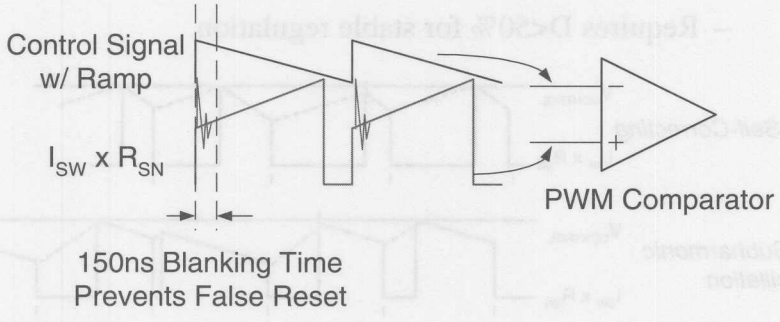
The LM3477, LM3478, and LM3488 controllers use current-mode control. This method controls the duty cycle of the regulator by directly sensing the switch current. In its simplest implementation, the switch current I_{SW} is turned into a voltage via a sense resistor R_{SN}, and compared to a control signal, usually the output of the error amplifier. In addition, current-mode control inherently provides cycle-by-cycle current limit, improving the reliability of the regulator.

By controlling the switch current, the output stage of the regulator appears to be current-fed rather than voltage-fed. Thus, instead of the output L-C adding a double-pole and a zero to the frequency response, it only adds a pole and zero due to the output capacitor. This simplifies the control loop, making it easier to stabilize.

However, current-mode control has one key problem area – if the control voltage is constant, and the switch current has a bit of noise or transient signal (or the current sense lines coming back from the sense resistor pick up radiated noise in the layout), AND the duty cycle starts out greater than 50%, the regulator can go into a subharmonic oscillation as it attempts to correct the output voltage.

LM3477, LM3478 Include Slope Comp.

- Many applications require D>50%
- To prevent subharmonic oscillation, LM3477 & LM3478 add compensating ramp to control voltage



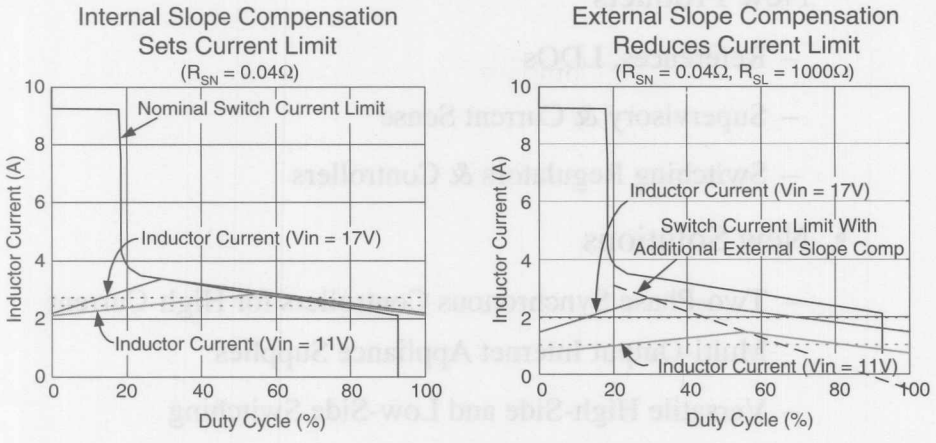
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Analog Applications 42

Because the LM3477, LM3478, and LM3488 are intended to be used in many applications, including those requiring over 50% duty cycle, they include an internal compensating ramp. This ramp is added to the control signal, so the control signal appears to be a sawtooth with negative slope. To prevent false reset of the duty cycle due to switching noise, the control signal has a 150ns blank-out time. This 150ns also becomes a minimum on-time for the regulator – 18% for 1.2MHz switching frequency.

In mathematical terms, the effect of the slope compensation is to increase the angle between the sense current signal and the control signal, to match the angle that would be seen with a duty cycle of less than 50% (and no slope comp.). This allows the system to be self-correcting, as if the duty cycle were less than 50%.

Compensating Ramp Includes Leading-Edge Blanking, Max. Duty Cycle Limit



LM3477 Buck Regulator Example, Vout=5V

The built-in compensation ramp also provides the switch current limit for the regulator. The current limit is set high during the initial 150ns, then drops to a normal control level for the typical operating range of 18% to 93% duty cycle. At duty cycle greater than 93%, the switch is forced off to reset the control system.

In the figure at the left, the blue line (Nominal Switch Voltage) is the maximum control voltage scaled for a R_{SN} value of 0.04ohm. The red line is the inductor current for a buck regulator, 17V input to 5V output running at maximum load current (average load current shown in red dotted line). The green line is the same inductor current with a lower input, 11V. Because the duty cycle at an 11V input is greater than for a 17V input, the switch current is limited to a lower value.

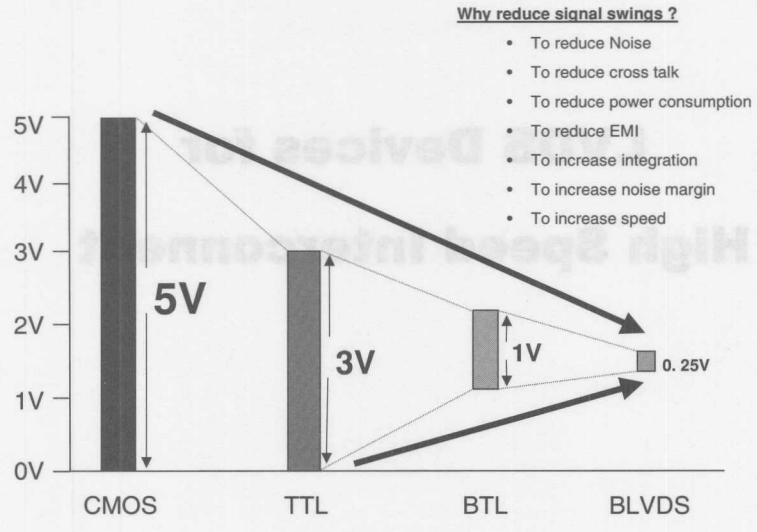
If the internal slope compensation is not sufficient, additional compensation can be added with an external resistor R_{SL}. The curve on the right shows the increased slope (and reduced current limit) with R_{SL} = 1kohm.

Power Management Products

- New Products
 - References, LDOs
 - Supervisory & Current Sense
 - Switching Regulators & Controllers
- New Solutions
 - Two-Phase Synchronous Controllers for High-Current Multi-Output Internet Appliance Supplies
 - Versatile High-Side and Low-Side Switching Controllers for Most Everything Else

LVDS Devices for High Speed Interconnect

Technology trends



National Semiconductor

Analog Applications 2

Switching an interconnect at high speed be it cables or PCB backplanes, is a big challenge. Historically, such interconnect has used "digital" signaling levels ….. Rail-to-rail CMOS 5V or more traditional totem pole output TTL swings. Such large signal swings are difficult to switch and control at high frequencies …… just by the Laws of Physics - high switching rates require high slew rates. High slew rates and large swings = a lot of energy (current switching). Such energy causes emissions (EMI) and also is difficult to manage (undershoots / overshoots / decoupling / et al).

BTL tried to alleviate the problem by reducing the amount of switching (reducing the swing to 1V), but the current involved with switching and the single ended nature of the technology still makes it non-ideal.

National invented Bus LVDS to provide the ideal solution. It is an evolution to our existing LVDS point-to-point technology. It inherits the benefits of LVDS (low swing, differential, low current) but with the capability of driving a low impedance double terminated bus ……

National's Bus LVDS

Bus LVDS is a no compromise solution :

- **high speed**
 - > 155 to 400 Mbps across a multipoint bus
- **low power**
 - 10mA loop current to switch the bus
- **low noise/EMI**
 - low swing differential signaling for low emissions
- **low cost**
 - pure CMOS design
 - simple bus implementation

Bus LVDS provides a no compromise solution for multipoint backplanes. It is capable of enabling a multipoint backplane, (i.e. a 20 slot, 0.9" spacing, FR4 - typical for a telecom system) to run :

* > 155Mbps : and lower - maximum multipoint rate is around 400Mbps. The limitation is the practicality of stub and loading effects which impacts the bandwidth capability of the backplane. [Reference DesignCon 99 White Paper at URL : http://www.national.com/appinfo/lvds/]

* Bus LVDS uses only 10mA to "switch" the backplane (see later slide)

* being low swing and differential - low noise is generated and there is good immunity to external sources of noise

* Bus LVDS is implemented in submicron CMOS technology - enabling high integration and low cost

Bus LVDS features

- **Fault tolerance is a "must" for a bus product.**
 Bus LVDS products have :
 - High impedance on power down
 - Hot insertion capability
 - Bus contention tolerance
- **Bus LVDS features**
 - Light bus loading (< 5pF)
 - Balanced output impedance (Do-/Do+)
- **Ruggedness**
 - > 2000V ESD to HBM
 - > +/- 300mA latch up

Data busses are a very critical part of a system - especially in a telecom system. Therefore there are some "must haves" as far as the Bus LVDS is concerned :

* fault tolerance is a "must". If power fails on a given device on any given card, it must go high Z as to not affect the operation of the bus. Also, a device must have the ability to be plugged into a "hot" system and not be damaged in National's application testing we have shown that Bus LVDS survives hot insertion but also does not corrupt the data on the bus either.

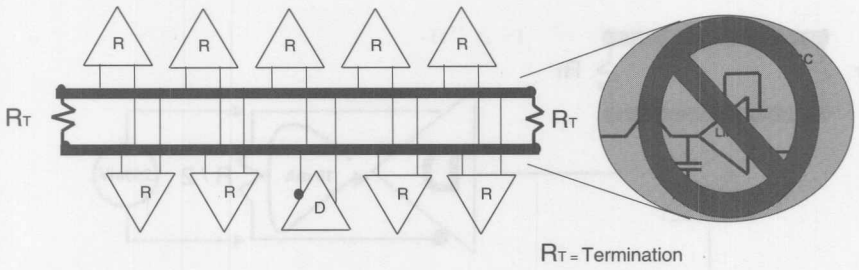
* in addition Bus LVDS has the features of :

- light bus loading each transceiver has low loading so as to not "load" the bus down.

- unlike LVDS, Bus LVDS has a more balanced driver output impedance which means that any reflections are more common mode in nature.

* as with any other bus technology, devices must also meet minimum ruggedness requirements of 2000V ESD Human Body Model (HBM) and +/-300mA latch up.

Greatly Simplified Terminations



BLVDS requires

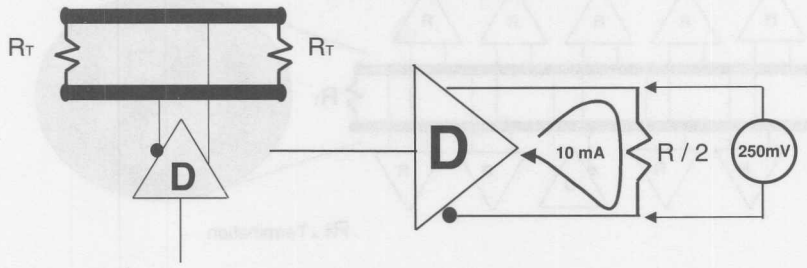
***NO** active devices*

***NO** secondary power supply (V_T)*

Only two passive resistors (R_T)

By using the basic concept of a constant current source driver (like LVDS) and differential (like LVDS) - a very simple bus termination scheme can be utilized (see above). Only two discrete differential termination resistors need be used. This is unlike other single / pseudo single ended technologies like BTL, GTL or ECL that require complicated, costly, power consuming and source of failure termination voltage schemes at each end of the bus.

Minimized Power Dissipation

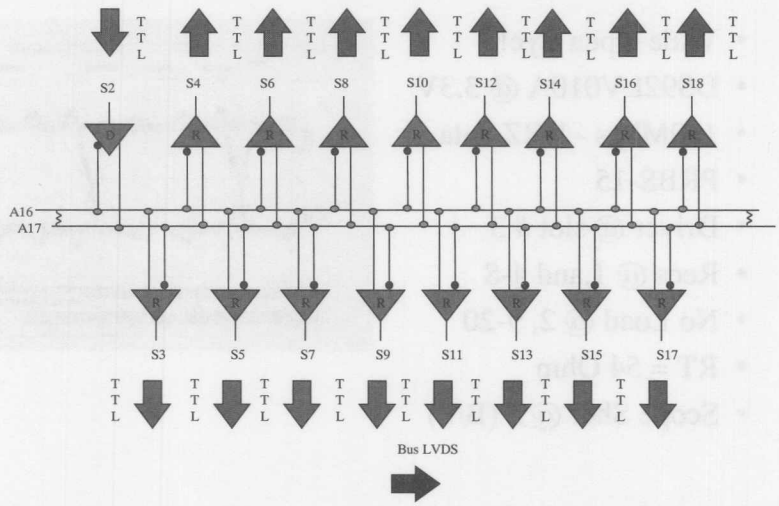


Power Load = I_{OD} X V_{OD} = 10 mA x 250 mV = **2.5 mW**

Bus LVDS switches the interconenct with typically only 10mA of current. With a 250mV swing this is only 2.5mW of power. This is an order of magnitude lower or more than other similar speed - or even lower speed - technologies that drive the bus with much high currents (> 30mA) and larger voltage swings (> 800mV).

Bus LVDS example

DS92LV010 Multipoint Differential Backplane



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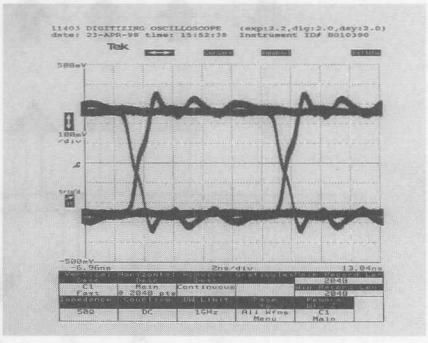
Analog Applications 7

National built a "typical" 20 slot backplane to test the initial transceiver (DS92LV010A) above. This showed very good results

[Further design tips for backplanes can be found at http://www.national.com/appinfo/lvds/. The DesignCon 2000 White Paper gives a good summary of design tips to be followed.]

Signal Quality @ 100Mbps

- Wide Open Eye!
- DS92LV010A @ 3.3V
- 100Mbps - NRZ data
- PRBS-15
- Driver @ slot # 3
- Recs @ 1,and 4-8
- No Load @ 2, 9-20
- RT = 54 Ohm
- Scope Shot @ 5 (B/P)



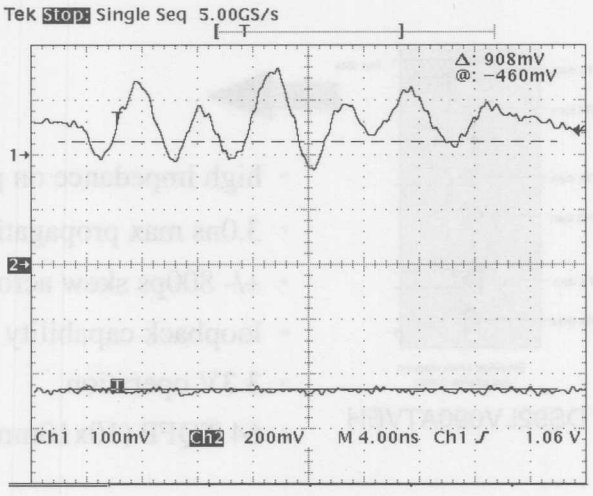
….. running the DS92LV010A at 100Mbps with a PRBS-15 pattern observed the following characteristics :

* good signal quality across the backplane

* inability to cause BER during hot insertion and removal

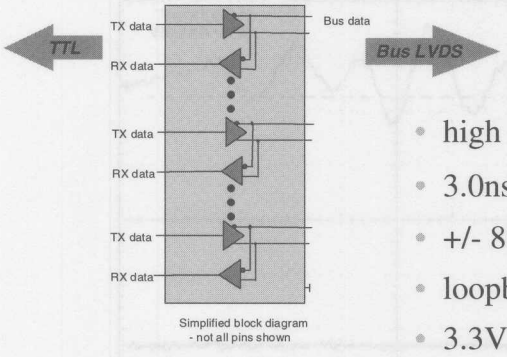
* inability to cause BER with unbalanced card loading in the backplane (empty / full slot variations)

Live Insertion Scope Waveshape



…. the above plot shows the effect of hot card insertion into a backplane. Top trace shows the single ended version of the signal during card insertion …. The bottom trace shows the differential version of the same event ….. No impact on data flow on the backplane.

9 Channel Transceiver



DS92LV090ATVEH

- high impedance on power down
- 3.0ns max propagation delay
- +/- 800ps skew across PVT
- loopback capability
- 3.3V operation
- 64 TQFP (10x10mm package)

National has now released it's 9 channel transceiver for driving multipoint backplanes. Some things to note about this part :

* it has all of the Bus LVDS features

* has a low Tpd max specification for low latency

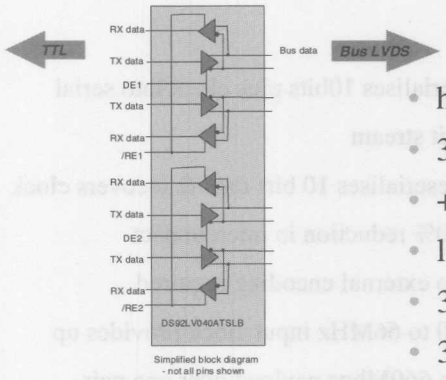
* it has a low channel to channel skew specification over process, voltage and temperature (PVT). This means that when multiple devices are placed in parallel in "wide word" applications, a low skew across the whole word is guaranteed by the datasheet specification

* the device also has loopback capability to enable readback

* the part is in production in TQFP - the SCAN92LV090VEH (the JTAG (IEEE1149.1) version)

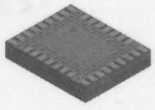
is available in BGA

4 Channel Transceiver



- high impedance on power down
- 3.2ns max propagation delay
- +/- 800ps skew across PVT
- loopback capability
- 3.3V operation
- 32 lead CSP (5.5mm x 4.5mm)

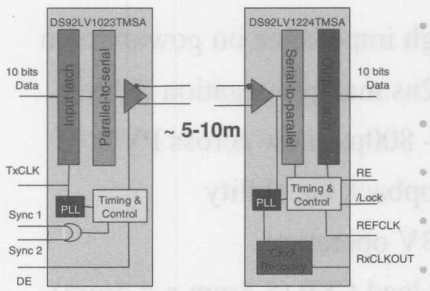
DS92LV040ATLQA



….. some applications need a wider datapath than just a single channel (where one would use the DS92LV010A single transceiver) but less than the 9 channel device.

National has developed the 4 channel version for such applications and is especially good for two channels of data / clock applications - IEEE1394 for example.

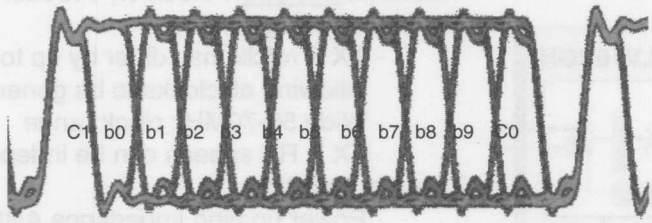
Serialiser/deserialiser chipset



- serialises 10bits plus clock into serial bit stream
- deserialises 10 bits data & recovers clock
- 80% reduction in interconnect
- no external encoding required
- 40 to 66MHz input clock provides up to 660Mbps payload over one pair
- < 200mA Icc for chipset

National's highly successful 10:1 serialiser / deserialiser chipset is now available at 66MHz clock frequency - 660Mbps data payload. This chipset is idea for point-to-point and multidrop applications where low wire interconnect count is most important.

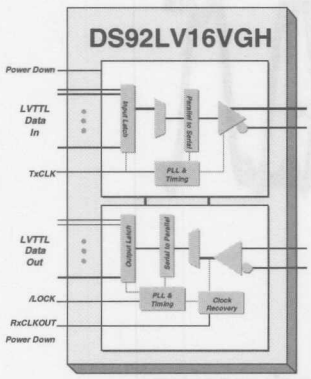
Data Payload = 660 Mbps



- **10 bits are sent every TCLK cycle**
 - **10 * 66 MHz = 660 Mbits / Sec**
- **2 clock bits added for deserializer clock recovery**
 - **2 * 66 MHz = 120 Mbits / Sec**
- **Total transmitted data is 780 Mbits / Sec**

The 66MHz serialiser takes a 10 bit word and serialises this onto one pair of wires. Along with the serialised data the associated clock is embedded in the same stream. This is done by inserting two "bits" in the serial stream ….. a "start bit" C1 and "stop bit" C0. It is these two bits that are used by the deserialiser to "frame" the serialised word and then deserialise it.

16 bit transceiver



- 1.22Gbps payload + clock on 1 robust LVDS pair
- Flexible clocking scheme
 - TX & refclk may differ by up to ±5%, allowing all clocks to be generated locally
 - Wide 50-70MHz clock range
 - TX & RX speeds can be independent
- True live insertion
 - Power up high impedance AND
 - Lock to random data (no K chars needed)
 - Once sync'd, byte alignment checked and reported every clock cycle
- Single 3.3V supply
 - Separate TX & RX power down pins
 - < 1W max power consumption
- No external PLL components
- Line & local loopback modes
- 80 lead PQFP, 12 x 12 x 1.4 mm

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Analog Applications 14

National has released a three types of LVDS ser/des to-date.

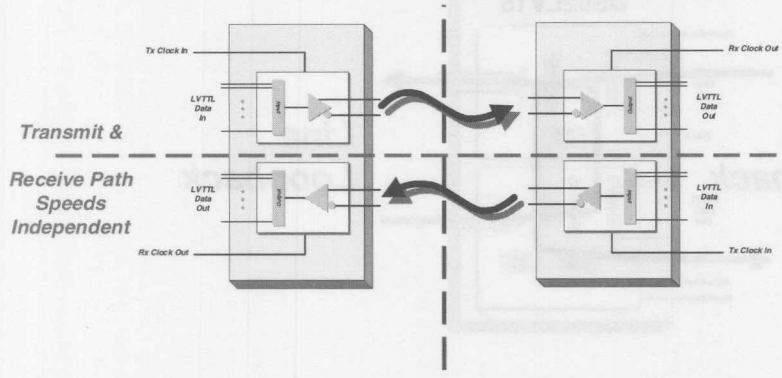
1) Channel Link uses a 7:1 serialisation scheme and transports the associated parallel clock in parallel with the serial datastream(s). There are three flavours of this - 21, 28 and 48 bit versions.

2) We have highlighted on the previous foils National's 10:1 serialiser / deserialiser.

3) Now, National's latest is a byte oriented serialiser / deserialiser and in a transmitter / receiver pair - the DS92LV16.

Clocking Independence

Transmit & RefCLK Can Differ by ±5%



- **Embedded clock means true clock recovery**
 - **Easy to use local clocking**
 - **Nodes can be fully independent**
- **Wide, independent 30-80MHz clock range for Tx and Rx paths**

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Analog Applications 15

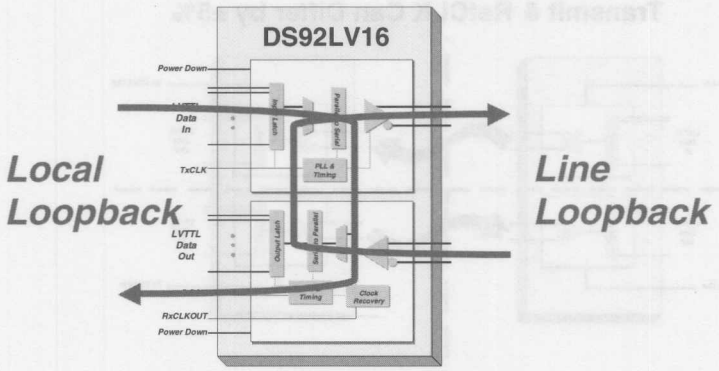
The DS92LV16 is a very flexible device. Unlike competition devices, the DS92LV16 can :

* run it's transmit and receive paths at completely independent speeds - within the min / max clock frequencies of the device. Competition devices have to run at the same TX and RX rates.

* have the RefCLK run at +/-5% of the transmit clock - unlike the tight PPM (parts per million) specifications required for competition's devices

* be configured as a TX only, RX only or TX/RX pair

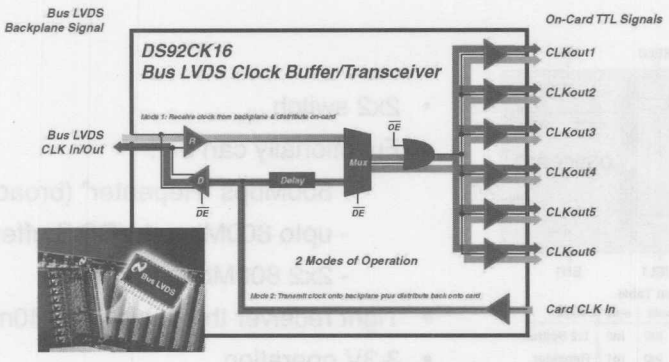
Local and Line Loopbacks



- Local and line loopback modes allow segregation of system for easier troubleshooting and testing

.... to aid system troubleshooting and test, the chip also has line and local loopback capability.

DS92CK16



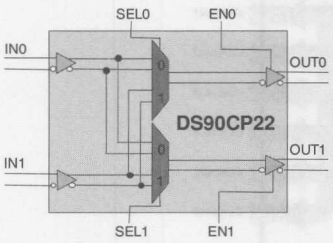
- DC to 125 MHz operation
- 50ps channel to channel skew
- Broadcast/receive from any card
- Slow Bus LVDS edge rates for low noise/EMI
- Bi-directional for central and source synchronous clock systems

The devices highlighted so far focused on the datapath. However, within a system, high speed clock distribution is also important. The DS92CK16 is a device that can :

a) "pick" a differential clock off a backplane and then translate it to six copies of a signal ended, ultra low skew clock that can be fed to ASICs / FPGAs "on card"

b) alternatively, take an "on card" clock and feed it out differentially onto a backplane (Bus LVDS)

DS90CP22



Function Table

sel0	sel1	out0	out1	Mode
0	0	in0	in0	1:2 Splitter
0	1	in0	in1	Repeater
1	0	in1	in0	Switch
1	1	in1	in1	1:2 Splitter

Note: en0 = en1 = 1 for enable

- 2x2 switch
- Functionally can be :
 - 800Mbps "Repeater" (broadcast)
 - upto 800Mbps LVDS "buffer"
 - 2x2 800Mbps switch
- Tight receiver thresholds (+/- 40mV)
- 3.3V operation
- High Z on power down (Vcc = 0V)
- 16 pin SOIC package

Many telecom systems require redundancy within a backplane. The DS90CP22 is an ideal device to support such redundancy. It can be used in two ways :

a) a serial input stream can be taken in on one of two ports and sent to two destinations (distribution)

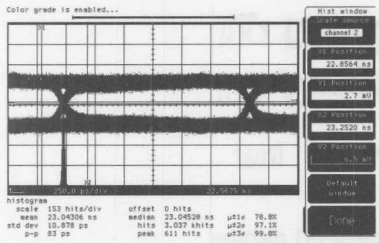
b) two inputs streams from two different destinations can be taken in and fed to one / two outputs

c) protection switching - switching between prime and redundant paths

d) as a true crossbar switch

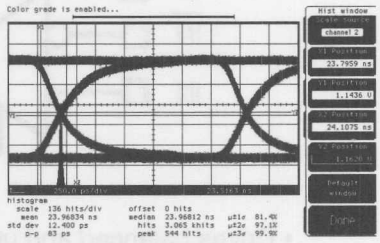
…. and all this is done with very low signal distortion ….

Eye patterns @ 622Mbps



Vos=0V
50mV/Div
250ps/Div

Jitter pk-pk=83ps without device



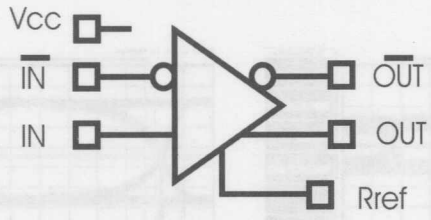
Vos=1.2V
100mV/Div
250ps/Div

Jitter pk-pk=83ps with device

…. the above plots show the very low signal distortion that the DS90CP22 introduces on a 622Mbps datastream.

….. and now the DS90CP22 is available in Industrial Temperature range : -40 to +85

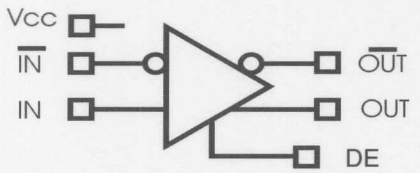
CLC001 - LVDS to PECL



- Drives balanced and unbalanced cables
- LVPECL, LVDS compatible inputs,
- Max data rate of 622 Mbps
- Adjustable output levels including 800 and 1000mV p-p
- Compliant with SMPTE 259M and ITU-T G.703
- 8-pin SOIC

National has received many requests for LVDS to PECL signal translation. Although this can be done discretely, National has released a monolithic device to do the job : the CLC001.

DS90LV001 - PECL to LVDS



- Drives balanced cables
- LVPECL, LVDS compatible inputs,
- Max data rate of 622 Mbps
- 8-pin SOIC / LLP
- 75% less PCB footprint when using LLP over SOIC

.... and the PECL to LVDS equivalent is the DS90LV001

National Semiconductor

Audio Group

Boomer® Audio Amplifiers for Cell Phones Lap Top Computers Information Appliances

National's Audio Group provides cost effective, low voltage audio amplifier solutions that are perfect for portable battery power devices such as cell phones, lap top computers, and information appliances. These products demand mono and stereo amplifiers that maximize size efficiency, maximize battery life, and offer high fidelity amplification. These requirements are achieved by National's Boomer® CMOS audio amplifiers.

National's High Performance Boomer® series Amplifiers

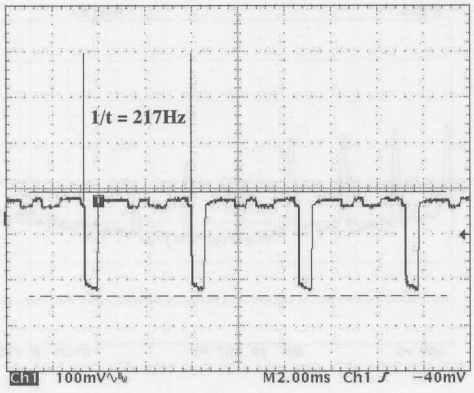
- Low operating supply voltage (2V - 5.5V)
- Low current consumption (CMOS based design)
- High Output power (105mW to 3W, SE and BTL)
- Widest selections of package types maximize board space:
 - SO
 - MSOP
 - TSSOP
 - micro SMD
 - Leadframe CSP (LLP)

National's Boomer amplifiers operate on a wide range of supply voltages: 2V to 5.5V. Designed to extend a portable product's battery life, they are built using low dissipation CMOS circuitry. With a range of output powers from 105mW to 3W, Boomers can meet the audio amplifier requirements of all battery powered portable devices.

National's Boomer amplifiers are offered in some of the most space efficient packages available today. These include SO and MSOP as well as the finer lead pitch found in the TSSOP. The ultimate in minimum package size is the LLP (Leadless Leadframe Package) and the micro SMD All of these package options ensure maximum PCB area efficiency.

Cell Phone Audio Application Hints

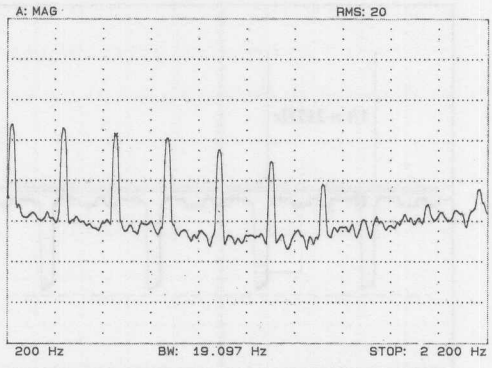
Power Supply Ripple



Typical power supply ripple in a GSM phone caused by the RF power amplifier

This is a scope photograph of a GSM cell phone's typical battery voltage level during "talk mode." The negative-going pulses have a typical magnitude of 200mV, repeating at a 217Hz rate. This noise will be audible in phones using audio amplifiers with poor low frequency PSRR.

"Bumble Bee" Noise

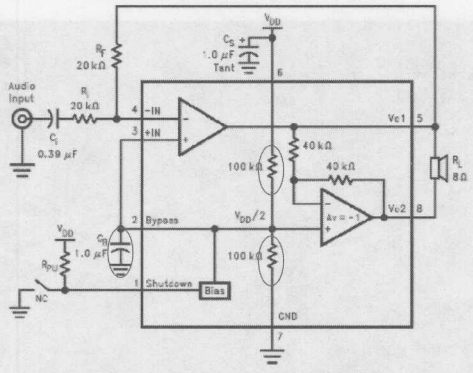


Voice band noise at the speaker terminals caused by low Power Supply Rejection Ratio

This is the result of connecting an audio amplifier with inadequate PSRR directly to the GSM cell phone battery. The 217Hz pulses produced while the phone is in talk mode produce an amplifier output whose spectrum is shown above. The 217Hz fundamental and its harmonics contaminate the output signal.

The traditional methods to suppress the 217Hz and its harmonics is by powering the audio amplifier with a regulated supply voltage and increasing the value of supply and the $V_{CC}/2$ bypass capacitors. However, these solution increase parts cost and in the case of increasing the $V_{CC}/2$ bypass capacitor, increase turn-on time. GSM cell phone designers want to connect an audio amplifier directly to the battery for power.

Improving PSRR



Traditional amplifier PSRR is determined by the 100K ohm voltage divider and C_{BYPASS}

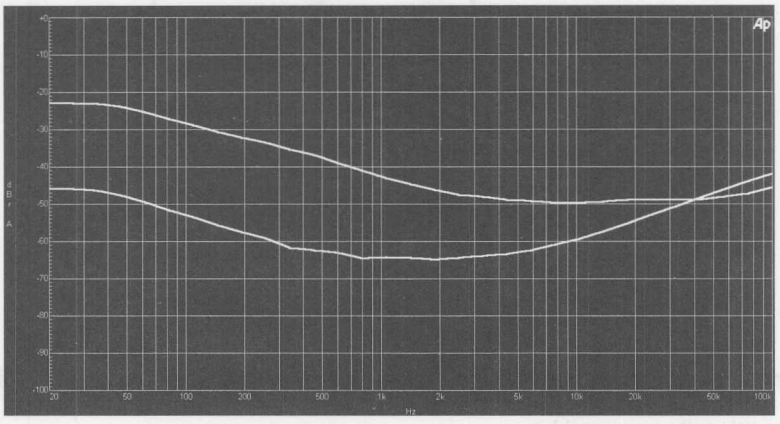
Traditionally improved by:

Increase C_{BYPASS} value (which results in longer turn-on time)

Increase internal resistor value (again, longer turn-on time)

In simple form, the internal circuitry that produces the $V_{CC}/2$ is a resistor divider between the supply input and ground. Because of this, PSRR is limited by the ripple present on the bypass pin. The traditional solution that increases the BYPASS capacitor's value actually degrades low frequency PSRR, right in the frequency bandwidth where GMS phones need the most help. Further, increased BYPASS capacitor values increase turn-on time (at "power-up" and return from shutdown). Further improvement in PSRR with acceptable turn-on time is achieved with the new LM4890 amplifier.

Improving PSRR



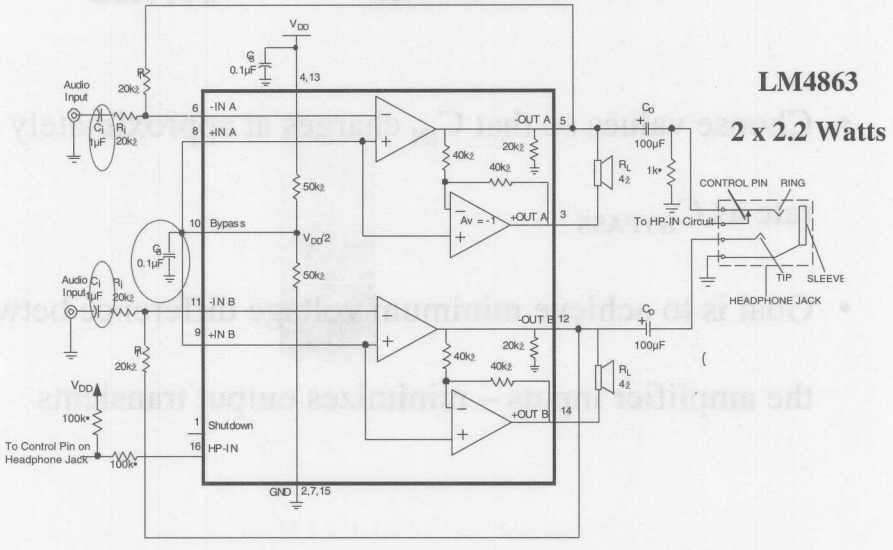
- Top trace is the PSRR of a traditional audio amplifier
- Bottom trace is the PSRR of the LM4890
- ***>25dB improvement at 217Hz!***

When compared to traditional single supply audio amplifiers, the LM4890 achieves a typical PSRR improvement of 25dB at 217Hz, a frequency common to GSM phones.

The conditions under which the two curves were generated:

$$V_{CC} = 3.3V,\ R_L = 8\Omega,\ C_{BYPASS} = C_{VCC} = 1.0\mu F,\ C_i = 0.39\mu F,\ R_{SOURCE} = 10\Omega.$$

Selecting C_{IN} and C_{BYPASS}



Output transients ("clicks and pops") are minimized by carefully selecting C_{IN} and C_{BYPASS} values

Typically, single supply, single-ended audio amplifiers have internal circuits that force the signal inputs to operate quiescently at one-half of the supply voltage. This requires capacitively coupled inputs. Further, to ensure low noise performance and improve PSRR, another external capacitor is use to bypass the internal half-supply bias circuitry. The presence of these capacitors may produce output transients when the power supply voltage is first applied. These transients are caused by charging the input coupling capacitors and the half-supply bypass capacitor.

From the Figure, it can be seen that C_{BYPASS} charges through a 50kΩ resistor and the input coupling capacitor charges through a 20kΩ resistor.

Boomer amplifiers feature a turn-on mute function that helps reduce the effects of output transients when the supply voltage is applied. The output of these parts remains muted until the voltage on C_{BYPASS} nears $V_{CC}/2$. When this occurs, the outputs are unmuted. The length of time between application of supply voltage and active output is referred to as turn-on time, and is directly proportional to the size of C_{BYPASS}.

The LM4863 is a stereo 2.2W power amplifier. It contains improved "click and pop" suppression circuitry and a switchable bridged/single-ended amplifier so that one set of amplifiers can be used for both speakers and headphones.

Selecting C_{IN} and C_{BYPASS}

- Choose values so that C_{IN} charges at approximately same rate as C_{BYPASS}
- Goal is to achieve minimum voltage difference between the amplifier inputs – minimizes output transients

The goal when choosing input coupling and $V_{CC}/2$ bypass capacitors is to minimize output transients. This is accomplished by having these capacitors charge at the same rate. By charging at the same rate, the differential voltage applied to the amplifier's inputs is minimized, thus producing little or no transients at the output.

There is a balancing act between minimizing output transients, turn-on time, and low frequency response. Achieving extended low frequency response may require a high value (0.47μF to 0.82μF) coupling capacitor. This then requires a C_{BYPASS} capacitor in the range of 3.3μF to 5.6μF to ensure minimum output transients. However, though this minimizes output transients, the turn-on time may be too long for a given application.

Selecting C_{IN} and C_{OUT}

- ***To minimize THD:***

 Best input coupling caps: *multilayer COG or NPO ceramic*

 Alternate choices: *X7R or X5R*

 Best input coupling caps (headphones): *aluminum electrolytic*

 Alternate choice: *tantalum (but more $)*

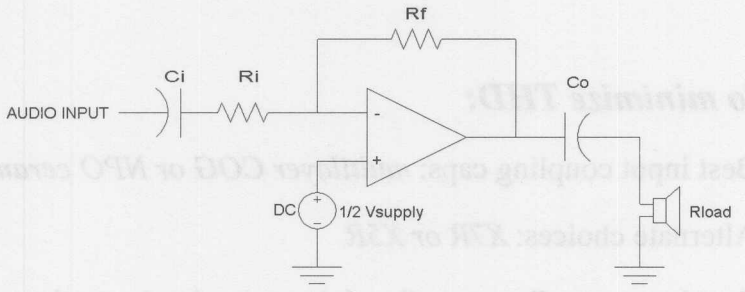
 C_{BYPASS} dielectric is not critical

Different capacitor dielectrics produce differing amounts of total harmonic distortion (THD). We have found that multilayer COG or NPO ceramics work best for input coupling capacitors. Alternatives that helps reduce cost are X7R or X5R capacitors.

For output coupling capacitors, needed for single-ended headphone drive, simple inexpensive aluminum electrolytic capacitors achieve the best fidelity. For applications where board size and parts density are important, tantalum capacitors can be substituted for the aluminum capacitors.

The dielectric used in the C_{BYPASS} and power supply bypass capacitors is not critical. Use whatever is most cost effective.

Voice Band Filtering



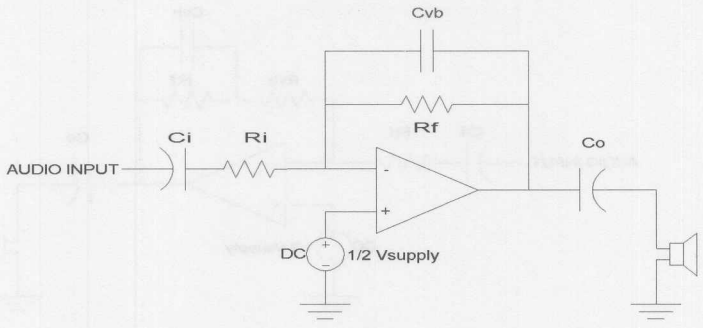
- Filtering frequencies below voice band
 - -R_i and C_i form 1ST-order highpass filter
 - Low frequency cutoff: $f = 1/(2pR_iC_i)$
 - -R_{LOAD} and C_O form 1ST-order highpass filter
 - Low frequency cutoff: $f = 1/(2pR_{LOAD}C_O)$

For applications that can take advantage of reduced audio bandwidth such as cordless and cell phones, the input coupling capacitor and resistor and the output coupling capacitor and load resistance can be used to form two first-order highpass voice band filters. As the bandwidth is restricted by making the capacitors lower value than would be used for full bandwidth, the value of C_{BYPASS} can also be decreased. This can help decrease board area and reduce cost.

The input highpass filter has a cutoff frequency equal to $1/(2\pi R_iC_i)$. The cutoff frequency of the output highpass filter is equal to $1/(2\pi R_{LOAD}C_O)$.

Another applications area where this is also advantageous is systems that drive small speakers having little or no output SPL at low frequencies.

Voice Band Filtering

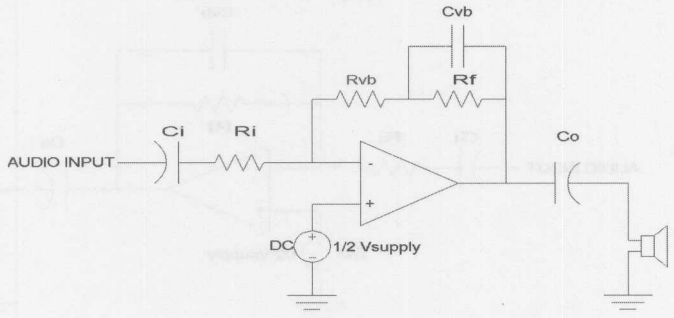


- Addition of C_{vb}
 - Filters frequencies beyond voice band
 - High cutoff frequency: $f = 1/(2pR_f C_{vb})$
 - Voice band gain: $A_V = R_f / R_i$
 - May cause amplifier instability at certain frequencies

The input and output coupling capacitors limit the low frequency response in systems that primarily handle voiceband frequencies. The lowpass filter needed to limit the upper voiceband response is accomplished by adding a capacitor in parallel with the amplifier's feedback resistor. The lowpass filter cutoff frequency is $1/(2\pi R_f C_{vb})$.

Adding the feedback capacitor creates the possibility of amplifier instability. The risk of instability is negated by adding a resistor as shown in the next slide.

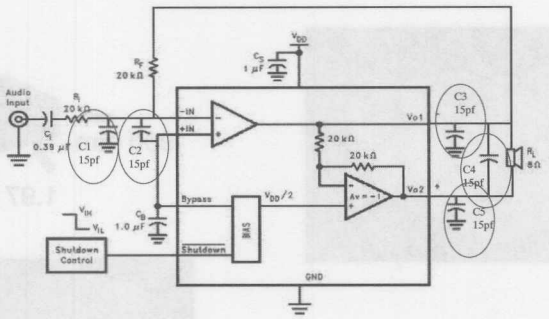
Voice Band Filtering



- Addition of R_{vb}
 - Improved amplifier stability alternative
 - High cutoff frequency: $f = 1/(2pR_fC_{vb})$
 - Voice band gain: $A_V = (R_f+R_{vb})/R_i$
 - High band gain: $A_V = R_{vb}/R_i$

The addition of R_{vb} ensures that the amplifier remains stable at high frequencies. The gain for frequencies in the voice band is now a function of the series combination of the two feedback resistors. As the input signal's frequency increases, C_{vb} shorts R_f, creating a high frequency gain that is a function of R_{vb} The input and output coupling capacitors perform the same function as in the previous circuit. The lowpass filter cutoff frequency is remains $1/(2\pi R_fC_{vb})$.

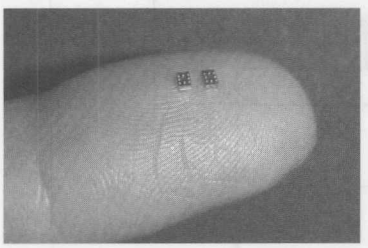
HF Noise-Suppression Caps



- C1-C5 may reduce high frequency noise at Vo1 and Vo2
- Use them only as a last resort and do not exceed 15pf
- If deemed necessary, add each capacitor one at a time, verifying effectiveness

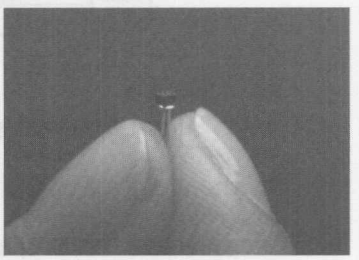
A typical method to reduce or prevent high frequency noise from degrading an audio amplifier's operation is through the application of small value capacitors applied to the inputs and outputs. While this indeed helps reduce noise, it can also lead to output oscillation. If they are used, limit their size to 15pF. And to ensure that their inclusion does not exacerbate the noise problem, place them in the circuit one at a time and observe the effectiveness of each capacitor. Once the problem as been satisfactorily corrected, add no more.

micro-SMD





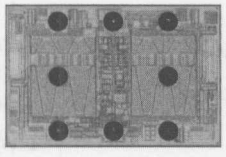
- Micro-SMD
 LM4872 IBP
 LM4877 IBP
 LM4890 IBP



Micro-SMD is a revolutionary new package being offered for the LM4872, LM4877, LM4890 and many future parts. It is a wafer level chip scale package (CSP). That is, a package designed to have external dimensions roughly equal to the silicon IC inside.

micro-SMD

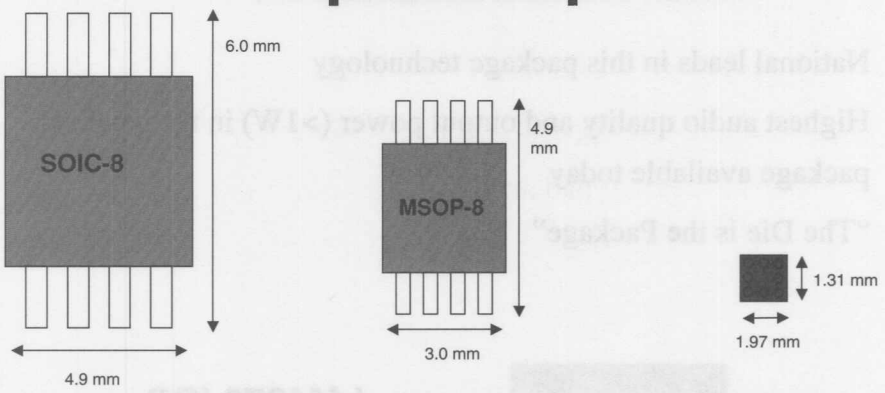
- National leads in this package technology
- Highest audio quality and output power (>1W) in the smallest package available today
- "The Die is the Package"



LM4872 IBP
Actual Die Photo
Total Area = 2.58 mm²

National leads the world in development of this package and the significant advantages it provides. High output power, high audio quality, miniscule size, and the ability to use standard surface mount assembly technology create highly desirable and cost-effective solution.

Footprint Comparison



LM4871M
1 W Boomer
29.4 mm²

LM4864MM
250mW Boomer
14.7 mm²

LM4872IBP
LM4877IBP
LM4890IBP
1 W Boomers
2.6 mm²

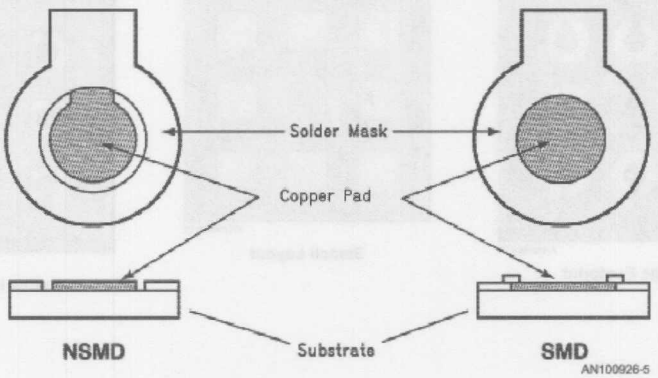
As can be seen from this comparison of 8-lead packages, the 8-bump micro SMD package uses roughly 1/6 the board area of the MSOP-8 and less than 1/11 of the area of the SOIC-8.

PCB Layout Guidelines

- micro SMD

 Non-Solder Mask-Defined (NSMD) pads

 1:1 size landing pad area vs. micro SMD bump diameter



Special considerations must be made when creating a PCB layout for micro SMD amplifiers. Typically, two types of land patterns are used for surface mount packages: solder mask defined and non-solder mask defined. Solder-mask defined pads have a solder mask opening that is smaller than the metal pad. Non-solder mask defined pads have a solder mask opening that is larger than the metal pad.

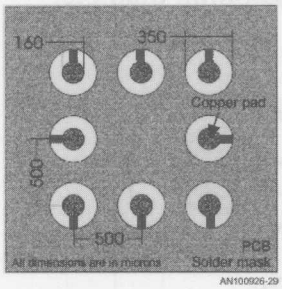
Non-solder mask defined pads are preferred for micro SMD because the copper etch process has tighter control compared to that of solder mask etch. Furthermore, solder mask defined pads can introduce stress concentration points near the solder mask that may result in solder joint cracking.

The copper pad should be the same diameter as the micro SMD's bump diameter.

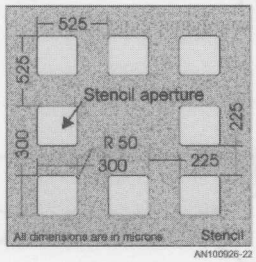
PCB Layout Guidelines

- micro SMD

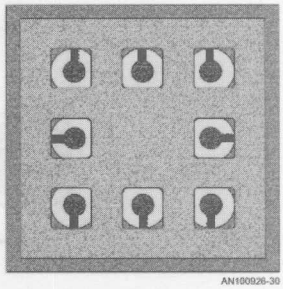
 Solder paste stencil apertures must be laser-cut



Package Footprint



Stencil Layout



Stencil laid over PCB

Solder paste deposition using a stencil-printing process involves transferring solder paste under pressure through pre-defined apertures. Of the three typical stencil fabrication methods -- chem-etch, laser cut, and metal additive -- the laser cut process followed by electro-polishing is preferred. This combination ensures smooth, tapered aperture walls that facilitate paste release. As shown on this 8-bump micro SMD package footprint and stencil layout, 0.300mm square apertures on a 0.125mm thick laser-cut stencil with electro-polished finish yield the required solder paste results. Additionally it is recommended that the stencil apertures are offset from copper pad locations. This maximizes separation between solder paste deposits, avoiding solder bridging.

PCB Layout Guidelines

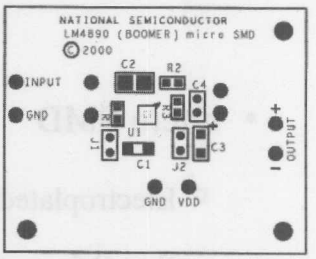
- micro SMD
 - ¤ Electroplated NiAu finish on board must be less than 0.5mm to avoid solder-joint embrittlement
 - ¤ See AN1112 for more information
 - ¤ Available for LM4890, LM4872, LM4877

Additionally, uniform PCB plating thickness is very important for high assembly yield. Thus, an electroplated nickel-immersion gold finish with a thickness of 0.15µm +/- 0.05µm is recommended. Also recommended is the use of a PCB with Organic Solderability Preserve (OSP) coating.

National Semiconductor application note AN1112 gives a detailed description of the layout and assembly requirements for micro SMD components. Micro SMD parts are easily handled with standard SMT pick-and-place, and high assembly yields are not difficult provided the notes detailed in AN1112 are followed.

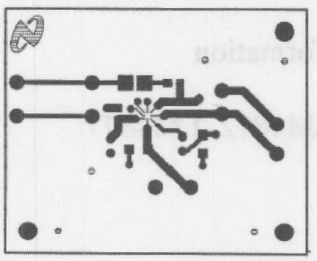
- *micro SMD*
 LM4890 demo board layout

Silk Screen



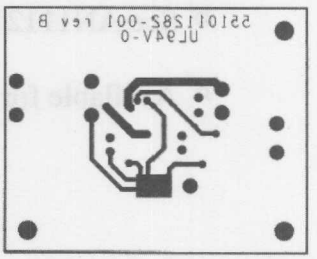
DS101310-57

Top Layer



DS101310-58

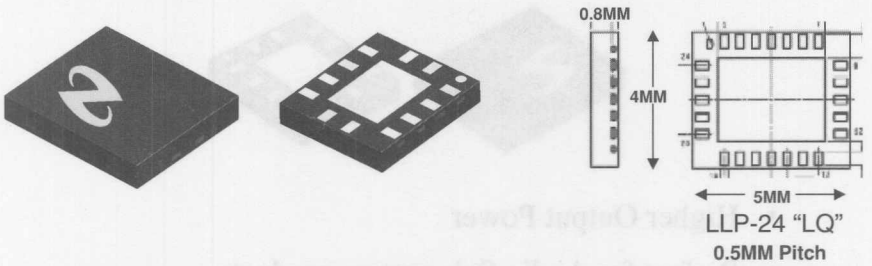
Bottom Layer

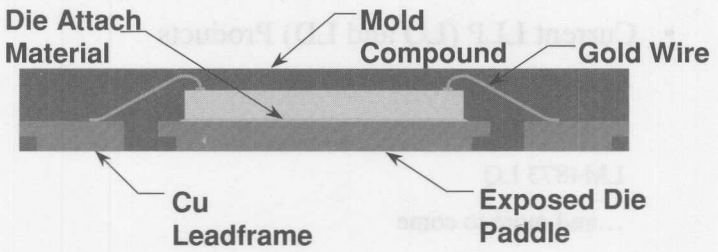


DS101310-59

The Figures above are the LM4890 demonstration board layout, showing the silk screen, top trace, and bottom trace layers. The micro SMD packaged LM4890 resides inside the silkscreen square above and to the right of the "U1" label. For size comparison, the square is about four times the area of the micro SMD package. Another comparison can be made with respect to resistor R3 (a 1206 sized SMD). The micro SMD LM4890 is about the same size as one of R3's solder pads.

NS Advanced Package Technology
Leadframe CSP (LLP)





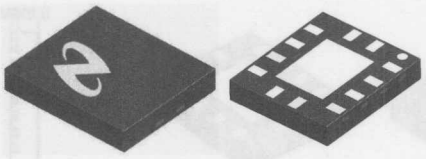
National Semiconductor

Analog Applications 23

The latest package National has introduced is the Leadless Leadframe Package (LLP). LLP packages offer a host of benefits over MSOP and SOIC packages including: reduced electrical parasitics, improved board space efficiency, reduced mount height, reduced package mass, lower thermal resistance, and low package cost.

As you can see, the LLP package has no protruding pins. Leads are accessed from the bottom of the chip, with the exposed die-attach paddle (DAP) shown in the bottom center of the chip. The exposed DAP is soldered down to the PCB just like the leads giving lower thermal resistance and enabling the PCB itself to serve as a heat sink.

Lead-less Lead Frame (LLP)



- Higher Output Power
- Perfect for Audio Sub-system products
- Current LLP (LQ and LD) Products

 LM4871 LD

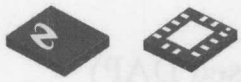
 LM4863 LQ

 LM4873 LQ

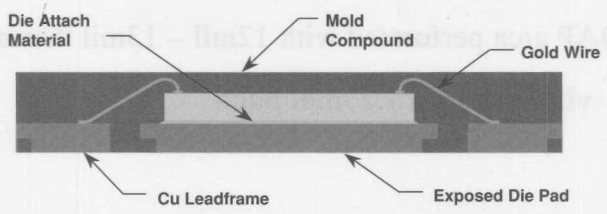
 …and more to come

The compact size of the package design along with the exposed die attach paddle greatly lowers thermal resistance, thus enabling greater power dissipation and higher output power versus other packages. This proves to be ideal for audio products where small board area and high output power are critical.

LM4871LD: 4871 in LLP



- P_{OUT} up to **3.0W**
- Package Size Reduction MSOP8 vs. LLP8 is **39%**



For comparison, consider the LM4871 in the LLP package. The LLP package has allowed us to re-classify the LM4871 as a 3W part (driving 3Ω at 10%THD) versus 1.2W in any other package (driving 8Ω at 1%THD). This output power would be impossible to achieve in any other package without operating in a freezer. In addition, the LLP package saves board space by 39% versus its MSOP counterpart.

- LLP (w/ exposed DAP)

 1:1 size landing pad area vs. LLP pin and DAP area

 Non-Solder Mask-Defined (NSMD) landing pads

 DAP area perforated with 12mil – 13mil thermal transfer via array on a 1.27mm pitch

The LLP package offers two outstanding advantages over other small, narrow lead-pitch packages: 0.5mm lead pitch and an exposed die attach paddle (DAP). The small package size and narrow lead pitch help minimize board space and the exposed DAP vastly improve the thermal capabilities over that of other non-exposed DAP packages. It is offered in two styles: a quad package with leads on all four sides and a DIP package with leads on two opposite sides.

To take complete advantage of these two important features, special consideration must be made when designing a PCB that uses an LLP packaged amplifier. The first consideration is, like the micro SMD, use non-solder mask defined pads to take advantage of tighter copper etch control and to prevent the chance of introducing stress concentration points near the solder mask that may result in solder joint cracking. The copper pad should have the same dimensions as the LLP's lead dimensions.

A second consideration is the use of a copper pad area on the PCB that is at least the same size as the LLP's DAP area. In the case of DIP LLP packages, the DAP pad can be larger than a package's DAP, extending to encompass a significant copper area. This extended area serves as a thermal mass and heat sink. A second heatsink area can be placed on an inner or bottom layer of a multilayer board. For a quad LLP package, the extended area is usually placed on an inner layer of a multilayer board or the bottom layer of a two sided board.

To ensure maximum heat transfer from the amplifier to the surrounding air, DAP to copper DAP pad is the first and most important interface to the package. When transferring heat to another board layer, a board's copper DAP pad must be perforated with an array of 12mil to 13mil thermal transfer vias that are set on a 1.27mm pitch.

PCB Layout Guidelines

- LLP (w/ exposed DAP)
 - Vias connect DAP to thermal mass/heatsink area (bottom side or inter-layer
 - Thermal mass/heatsink area: ≥40x package area
 - Even for the largest package (7mm x 7mm), heatsink area is 45mm x 45mm
 - 0.05µm – 0.127µm gold plating

The amount of thermal mass/ heatsink area needed to dissipate the heat generated in a Boomer amplifier packaged in the LLP is quite modest. Whereas a suggested area that is 40 times greater than the package area may at first seem very large, it is in fact only 45mm x 45mm for even the largest, currently available LLP (7mm x 7mm). A larger area provides no significant reduction in thermal resistance.

Uniform PCB plating thickness is very important for high assembly yield. Thus, an electroplated nickel-immersion gold finish with a thickness of 0.05µm - 0.127µm is recommended. Also recommended is the use of a PCB with Organic Solderability Preserve (OSP) coating.

PCB Layout Guidelines

- LLP (w/ exposed DAP)

 -Solder Stencil:

 DAP stencil dimensions are 0.95 package DAP dimensions

 Pin stencil dimensions are 1-to-1, offset 0.1mm away from DAP

 For DAPs with any side larger than 5mm, split stencil opening into two equal areas separated by 0.5mm

 See **AN1187** for more information

Some considerations must be given to the creation of the solder mask used on a PCB that employs LLP packages. The following three considerations help to ensure that the chance of solder bridges developing during board assembly are minimized. The solder mask that defines the amount of solder paste applied to the DAP pad should have dimensions that are 0.95 times the pad actual dimensions. The mask should be centered over the pad. The mask that places solder paste on the pin pads should have the same dimensions as the pad, but offset 0.1mm away from the DAP pad. DAPs that are larger than 5mm on any side require a solder paste stencil that is divided into two equal areas separated by 0.5mm.

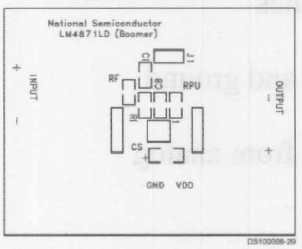
National Semiconductor application note AN1187 gives a detailed description of the layout and assembly requirements for LLP surface mount components. LLP packaged parts are easily handled with standard SMT pick-and-place, and high assembly yields are not difficult provided the notes detailed in AN1187 are followed.

PCB Layout Guidelines

- LLP (w/ exposed DAP)

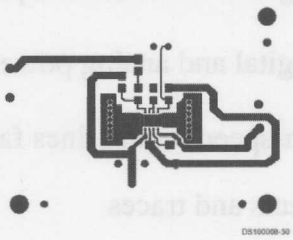
LM4871 demo board layout

Recommended LD PC Board Layout:
Component-Side Silkscreen



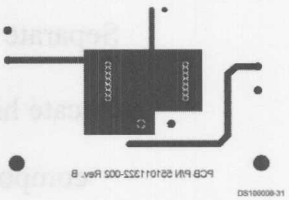
DS100008-29

Recommended LD PC Board Layout:
Component-Side Layout



DS100008-30

Recommended LD PC Board Layout:
Bottom-Side Layout



DS100008-31

This is the demonstration board layout for the LLP packaged LM4871. This mono Boomer amplifier will force 3W of dissipation across a 3Ω load. It will do so with only the heatsink area shown above. The actual board dimensions are 42mm by 51mm. The top layer demonstrates extending the DAP pad to increase dissipation mass and area. The bottom layer shows how heat is transmitted through the package with the via array beneath the package and dissipated with an additional mass and area.

PCB Layout Guidelines

- General Guidelines

 Star grounding

 90° crossing of traces between planes

 Separate digital and analog power and ground

 Locate high-speed digital lines far from analog components and traces

A Boomer's performance is maximized by using the time tested layout rules shown above.

LM4867 Boomer®

Patent Pending POP-LESS, CLICK-LESS Technology
Dual 2.1W Audio Power Amp & Stereo Headphone Mode

LM4867 KEY FEATURES

- 2 input MUX with individual Gain Setting
- Pop-Click Elimination circuitry !!
- Pin Compatible to LM4873 in both MT and LQ packages
- Minimal Externals -
 - No Bootstraps, Snubbers,
 - No Output Coupling Caps for speaker or headphone use
- Thermal shutdown protection
- Will be available in both MT/MTE & LQ packages

LM4867 OUTPUT POWER

•LM4867LQ
- 2.4W @1.0% THD (Vcc=5V, R_L=3ohm)
- 2.1W @1.0% THD (Vcc=5V, R_L=4ohm)

LM4867MT/MTE
- 1.9W @1.0% THD (Vcc=5V, R_L=4ohm)
- 1.1W @1.0% THD (Vcc=5V, R_L=8ohm)

Stereo Headphone Mode
- 75mW @ 0.5% THD (Vcc=5V, R_L=32ohm)

Low-Current Shutdown Mode
- (I_{SD} = 0.7μA), SD=High

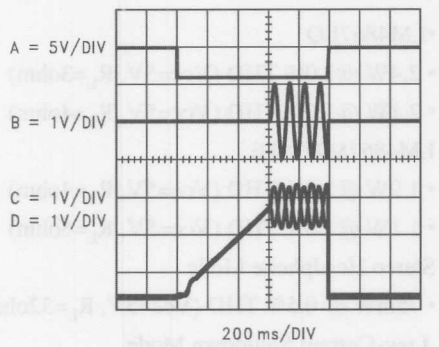
National Semiconductor

The LM4867 is a dual bridge-connected audio power amplifier which, when connected to a 5V supply, will deliver 2.1W to a 4Ω load or 2.4W to a 3Ω load with less than 1.0% THD+N. The LM4867 uses advanced, latest generation circuitry to eliminate all traces of clicks and pops when the supply voltage is first applied. The amplifier has a headphone-amplifier-select input pin. It is used to switch the amplifiers from bridge to single-ended mode for driving headphones. A new circuit topology eliminates headphone output coupling capacitors. A MUX control pin allows selection between the two sets of stereo input signals. The MUX control can also be used to select between two different customer-specified closed-loop responses.

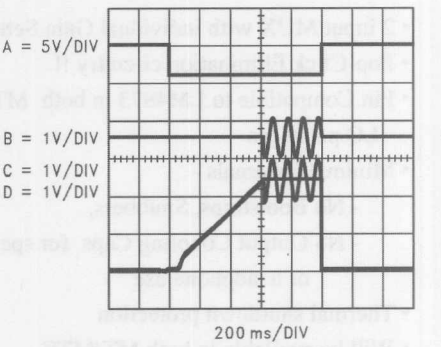
Boomer audio power amplifiers are designed specifically to provide high quality output power from a surface mount package and require few external components. To simplify audio system design, the LM4867 combines dual bridge speaker amplifiers and stereo headphone amplifiers in one package.

The LM4867 features an externally controlled power-saving 0.7μA micro power shutdown mode, a stereo headphone amplifier mode, and thermal shutdown protection. It uses a 24-pin quad LLP package, as well as the 20-pin MT and exposed-DAP MTE TSSOP packages.

LM4867 CLICK-POP PERFORMANCE



BTL Output Load



SE Output Load

The LM4867 contains advanced circuitry that eliminates output transients ('pop and click'). This circuitry prevents all traces of transients when the supply voltage is first applied, when the part resumes operation after shutdown, or when switching between BTL speakers and SE headphones. Two circuits combine to eliminate pop and click. One circuit mutes the output when switching between speaker loads. Another circuit monitors the input signal. It maintains the muted condition until there is sufficient input signal magnitude to mask any remaining transient that may occur.

The Figure on the left shows the LM4867's lack of transients in the differential signal (Trace B) across a BTL 8Ω load. The LM4867's active-high SHUTDOWN pin is driven by the logic signal shown in Trace A. Trace C is the VOUT- output signal and trace D is the VOUT+ output signal. The shutdown signal frequency is 1Hz with a 50% duty cycle. The Figure on the right is generated with the same conditions except that the output drives a 32Ω single-ended (SE) load. Again, no trace of output transients is seen.

LM4867 CLICK-POP PERFORMANCE

(using recommended external circuit components and operating mode)

- •No pop or click upon Power Turn On with or without input signal
- • No pop or click upon Power Turn Off if Shutdown active prior to power down
- • No pop or click when returning from Shutdown with or without input signal *
- • No pop or click DUE TO LM4867 when entering Shutdown mode with or without input signal.

The input coupling capacitor has an affect on the LM4867's click and pop performance. When the supply voltage is first applied to typical amplifiers, a transient (pop) is created as the amplifier's output charges the input capacitor from zero to a quiescent state (usually $V_{DD}/2$). The magnitude of the pop is directly proportional to the input capacitor's size. Higher value capacitors need more time to reach a quiescent DC voltage. Thus, pops can be minimized by selecting an input capacitor value that is no higher than necessary to meet the desired -3dB frequency and, in the case of the LM4867, is between 0.14 and 0.20 times the size of the $V_{DD}/2$ bypass capacitor (C_{BYPASS}).

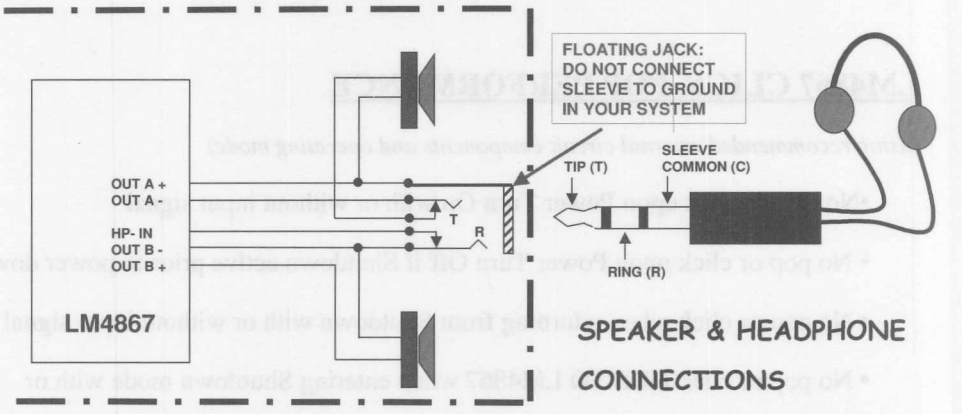
Careful consideration should be paid to value of C_{BYPASS}. Since C_{BYPASS} determines how fast the LM4867 settles to quiescent operation, its value is critical when minimizing turn-on pops. The slower the LM4867's outputs ramp to their quiescent DC voltage,the smaller the turn-on pop. Setting C_{BYPASS} equal to 1.0μF, along with a 0.1μF to 0.39μF input coupling capacitor (C_i), produces a click-less and pop-less shutdown function. Choosing C_i no larger than necessary for the desired bandwidth helps minimize clicks and pops. C_{BYPASS}'s value should be in the range of 5 times to 7 times the value of C_i . This ensures that output transients are eliminated when power is first applied or the LM4867 resumes operation after shutdown.

Following the above recommendation will ensure the correct operation of the LM4867's transient suppression circuitry in the four case detailed in the Figure above.

LM4867 Boomer®

Patent Pending POP-LESS, CLICK-LESS Technology

Dual 2.1W Audio Power Amp & Stereo Headphone Mode



- **No Output Coupling Capacitors Required for Headphone Mode !!**
- **System Cost Reduction**

National Semiconductor

Analog Applications 34

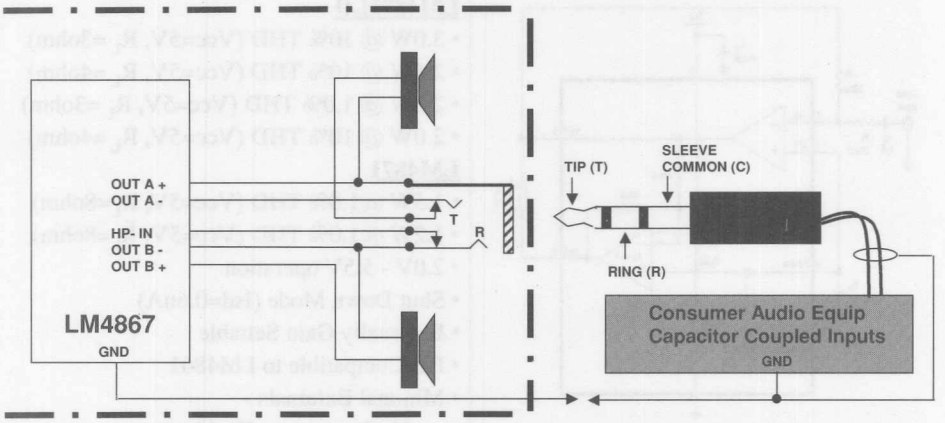
Typical single-supply audio amplifiers that can switch between driving bridge-tied-load (BTL) speakers and single-ended (SE) headphones use a coupling capacitor on each SE output. This capacitor blocks the half-supply voltage to which the output amplifiers are typically biased and couples the audio signal to the headphones. The signal return to circuit ground is through the headphone jack's sleeve.

The LM4867 eliminates these coupling capacitors. The OUT A+ output drives the stereo headphone jack's sleeve to $V_{DD}/2$ when the LM4867 operates in SE mode. This voltage matches the quiescent voltage present on the OUT A- and OUT B- outputs that drive the headphones. The headphones operate in a manner very similar to a bridge-tied-load (BTL). The same DC voltage is applied to both sides of each headphone speaker, resulting in no net DC current.

LM4867 Boomer®

Patent Pending POP-LESS, CLICK-LESS Technology

Dual 2.1W Audio Power Amp & Stereo Headphone Mode

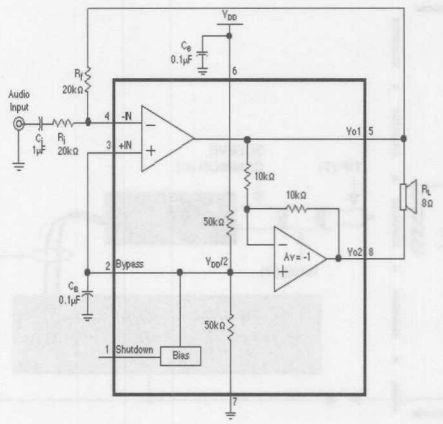


• No problem connecting to external consumer audio equipment under *common* GND condition when using Headphone Jack as Line Out !!

When operating as a headphone amplifier, the headphone jack sleeve is not connected to circuit ground. Using the headphone output jack as a line-level output will place the LM4867's one-half supply voltage on a plug's sleeve connection. Driving a portable notebook computer or audio-visual display equipment is possible. This presents no difficulty when the external equipment uses capacitively coupled inputs. For the very small minority of equipment that is DC-coupled, the LM4867 monitors the current supplied by the amplifier that drives the headphone jack's sleeve. If this current exceeds $500mA_{PK}$, the amplifier is shutdown, protecting the LM4867 and the external equipment.

Higher Power LM4871 Boomer®

3.0W Audio Power Amp with shutdown



National Semiconductor

LM4871LD

- 3.0W @ 10% THD (Vcc=5V, R_L=3ohm)
- 2.5W @ 10% THD (Vcc=5V, R_L=4ohm)
- 2.3W @ 1.0% THD (Vcc=5V, R_L=3ohm)
- 2.0W @ 10% THD (Vcc=5V, R_L=4ohm)

LM4871

- 1.5W @1.0% THD (Vcc=5V, R_L=8ohm)
- 1.2W @1.0% THD (Vcc=5V, R_L=8ohm)
- 2.0V - 5.5V operation
- Shut Down Mode (Isd=0.6uA)
- Externally Gain Settable
- Pin Compatible to LM4861
- Minimal Externals -
 No Bootstraps, Snubbers,
 No Output Coupling Caps
- Available in LD, SO-8 or 8 Pin Dip Package

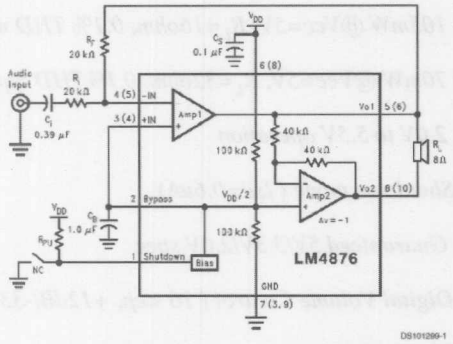
The LM4871 is a mono bridged audio power amplifier capable of delivering 3W of continuous average power into a 3Ω load with less than 10% THD when powered by a 5V power supply (in a properly mounted LLP package). To conserve power in portable applications, the LM4871's micro power shutdown mode (I_Q = 0.6μA, typ) is activated when VDD is applied to the SHUT-DOWN pin.

Boomer audio power amplifiers are designed specifically to provide high power, high fidelity audio output. They require few external components and operate on low supply voltages from 2.0V to 5.5V. Since the LM4871 does not require output coupling capacitors, bootstrap capacitors, or snubber networks, it is ideally suited for low-power portable systems that require minimum volume and weight.

Additional LM4871 features include thermal shutdown protection, unity-gain stability, and external gain set.

LM4876 Boomer®

1.1W Audio Power Amp with Active low shutdown



- 1.1W @ Vcc=5V, R_L=8ohm, 0.5% THD
- 1.5W @10%THD
- 2.0V to 5.5V operation
- Shutdown mode (Iq =0.01uA)
- **Active Low Shut Down logic**
 - **No external circuitry is needed when interface with an active low output control circuit**
- Externally Gain Settable
- Available in SO-8, MSOP-10 package

National Semiconductor

The LM4876 is a single 5V supply bridge-connected audio power amplifier capable of delivering 1.1W(typ) of continuous average power to an 8Ω load with 0.5% THD.

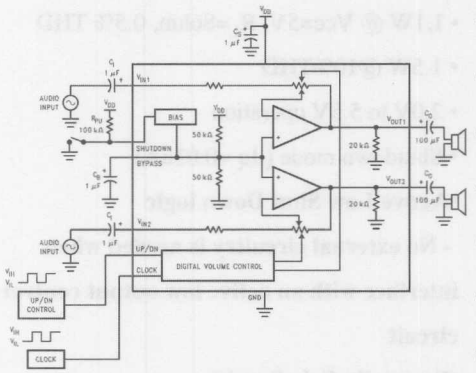
Like other audio amplifiers in the Boomer series, the LM4876 is designed specifically to provide high quality output power with a minimal amount of external components. The LM4876 does not require output coupling capacitors, bootstrap capacitors, or snubber networks. It is perfectly suited for low-power portable systems.

The LM4876 features an **active low** externally controlled, **micro-power shutdown** mode. Additionally, the LM4876 features an internal thermal shutdown protection mechanism. For PCB space efficiency, the LM4876 is available in MSOP and SO surface mount packages.

The unity-gain stable LM4876's closed loop gain is set using external resistors.

LM4811 Boomer®

Dual 105mW Headphone Amplifier with Digital Volume



- *105mW @Vcc=5V, R_L=16ohm, 0.1% THD max*
- *70mW @Vcc=5V, R_L=32ohm, 0.1%THD typ*
- *2.0V to 5.5V operation*
- *Shutdown mode (Isd=0.6uA)*
- *Guaranteed 5V/3.3V/2.6V spec*
- *Digital Volume Control (16 step, +12dB/-33dB, Clk, Up/Dn)*
- *Minimal External Components*
- *Available in LLP & MSOP 10 Package*

National Semiconductor

The LM4811 is a dual audio power amplifier capable of delivering 105mW per channel of continuous average power into a 16Ω load with 0.1% (THD+N) from a 5V power supply.

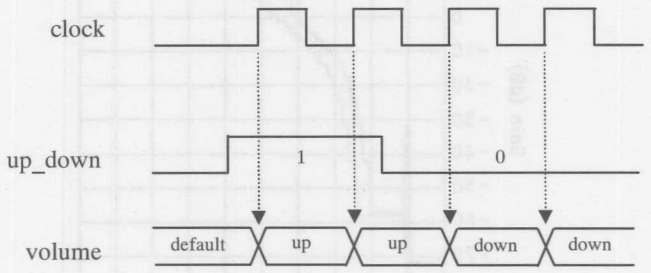
Boomer audio power amplifiers were designed specifically to provide high quality output power with a minimal amount of external components. Since the LM4811 does not require bootstrap capacitors or snubber networks, it is optimally suited for low-power portable systems.

The LM4811 features a digital volume control that sets the amplifier's gain from +12dB to -33dB in 16 discrete steps using a two-wire interface.

The unity-gain stable LM4811 also features an externally controlled, active-high, micro power consumption shutdown mode. It also has an internal thermal shutdown protection mechanism.

LM4811 Boomer®

Dual 105mW Headphone Amplifier with Digital Volume



Stereo Headphone driver with variable attenuation (gain) via 2 line digital interface

16 steps of volume adjusting (+12dB to -33dB)

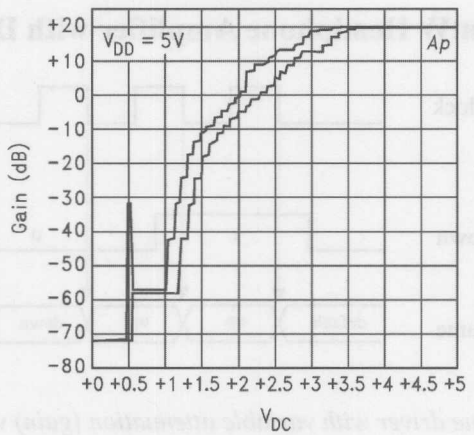
Package: 10 lead MSOP

The LM4811's gain is controlled by the signals applied to the CLOCK and UP/DN inputs. An external clock is required to drive the CLOCK pin. At each rising edge of the clock signal, the gain will either increase or decrease by a 3dB step depending on the logic voltage level applied to the UP/DN pin. A logic high voltage level applied to the UP/DN pin causes the gain to increase by 3dB at each rising edge of the clock signal. Conversely, a logic low voltage level applied to the UP/DN pin causes the gain to decrease 3dB at each rising edge of the clock signal. For both the CLOCK and UP/DN inputs, the trigger point is 1.4V minimum for a logic high level, and 0.4V maximum for a logic low level.

There are 16 discrete gain settings ranging from +12dB maximum to -33dB minimum. Upon device power on, the amplifier's gain is set to a default value of 0dB. However, when coming out of shutdown mode, the LM4811 will revert back to its previous gain setting.

The LM4811's CLOCK and UP/DN pins should be de-bounced in order to avoid unwanted state changes during transitions between VIL and VIH . This will ensure correct operation of the digital volume control. A microcontroller or microprocessor output is recommended to drive the CLOCK and UP/DN pins.

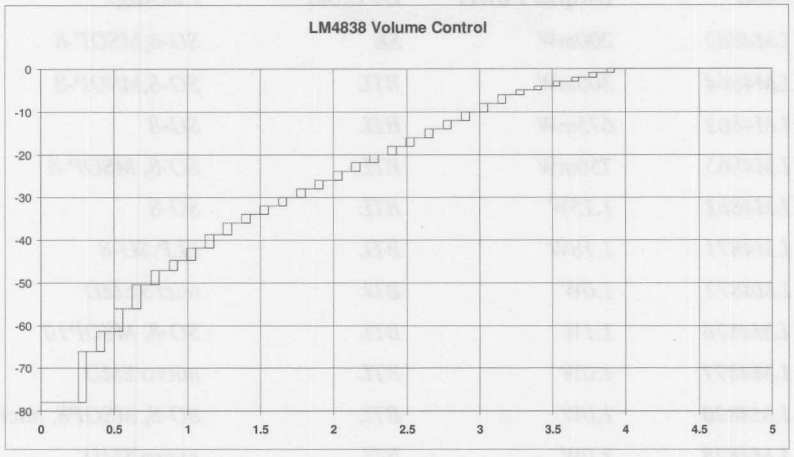
DC Volume Control



- *First generation DC voltage volume control*
- *Wide tolerance part-to-part matching*
- *NOT designed for accurate gain setting*

Like all volume controls, the first generation internal volume control is set while listening to an amplified signal that is applied to an external speaker. The actual voltage applied to the DC volume control pin is a result of the volume a listener desires. As such, the volume control is designed for use in a feedback system that includes human ears and preferences. This feedback system operates quite well without the need for accurate gain. The user simply sets the volume to the desired level as determined by their ear, without regard to the actual DC voltage that produces the volume. Therefore, the accuracy of the volume control is not critical, as long as volume changes monotonically and step size is small enough to reach a desired volume that is not too loud or too soft. Since gain accuracy is not critical, there will be volume variation from part-to-part even with the same applied DC control voltage. The gain of a given amplifier using the first generation volume control can be set with a fixed external voltage, but another amplifier may require a different control voltage to achieve the same gain. The Figure above is a curve showing the volume variation of twenty typical amplifiers as the voltage applied to the DC volume control pin is varied. For gains greater than unity, the typical part-to-part variation can be as large as 15dB for the same control voltage.

Improved DC Volume Control



The second generation DC volume control, found in the LM4838 and LM4839 stereo Boomer amplifiers, achieves improved accuracy. From part-to-part, the gain match is typically 2dB – 4dB over much of the control range versus the first generation control's 10dB to 15dB variance. Additionally, this new volume control features a 78dB range that has an optimized audio taper.

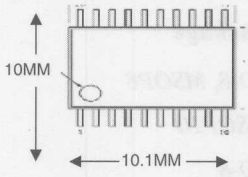
Boomer® Family Summary
Mono Output

Nsid	*Output Power*	*BTL/SE*	*Package*
LM4882	*200mW*	*SE*	*SO-8,MSOP-8*
LM4864	*300mW*	*BTL*	*SO-8,MSOP-8*
LM4862	*675mW*	*BTL*	*SO-8*
LM4865	*750mW*	*BTL*	*SO-8, MSOP-8*
LM4861	*1.15W*	*BTL*	*SO-8*
LM4871	*1.18W*	*BTL*	*LLP,SO-8*
LM4872	*1.0W*	*BTL*	*micro SMD*
LM4876	*1.1W*	*BTL*	*SO-8, MSOP10*
LM4877	*1.0W*	*BTL*	*micro SMD*
LM4820	*1.0W*	*BTL*	*SO-8, MSOP8, micro SMD*
LM4878	*1.0W*	*BTL*	*micro SMD*
LM4890	*1.0W*	*BTL*	*SO-8, MSOP8, micro SMD*

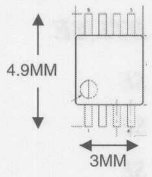
Boomer® Family Summary
Stereo Output

Nsid	*Output Power*	*BTL/SE*	*Package*
LM4808	*105mW*	*SE*	*SO-8, MSOP8*
LM4811	*105mW*	*SE*	*MSOP10*
LM4880	*250mW*	*SE*	*SO-8*
LM4881	*200mW*	*SE*	*SO-8,MSOP-8*
LM1877	*1.3W*	*SE*	*S0-14, DIP-16*
LM4863	*2.2W*	*BTL*	*LLP, SO-16,TSSOP-20*
LM4873	*2.1W*	*BTL*	*LLP, SO-16,TSSOP-20*
LM4867	*2.1W*	*BTL*	*LLP, TSSOP-20*
LM4838	*2.1W*	*BTL*	*LLP, TSSOP-20*
LM4839	*2.1W*	*BTL*	*LLP, TSSOP-20*

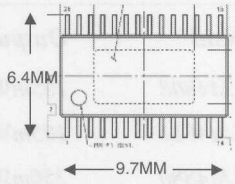
NS Audio Product
Surface Mount Package Technology



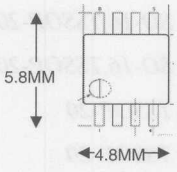
SO16 "M"
1.27MM Pitch



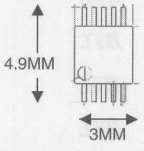
MSOP-8 "MM"
0.65MM Pitch



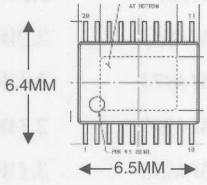
TSSOP-28 "MTE-1"
0.65MM Pitch



SO8 "M"
1.27MM Pitch



MSOP-10 "MM"
0.5MM Pitch



TSSOP-20 "MT,MTE"
0.65MM Pitch

Data Conversion Systems

National's Data Conversion Systems product line designs and manufactures:

- High speed ADCs (analog-to-digital converters)
- Temperature Sensors (temperature-to-analog and temperature-to-digital converters)

and highly integrated application specific products leveraging its leading-edge IP building blocks:

- System Health Monitors
- CMOS Image Sensors for Consumer and Industrial Cameras
- Analog Front Ends for Cameras and Scanners
- Complete Scanner Systems-on-a-Chip

Imaging at National Semiconductor

History

Camera AFEs

CMOS Image Sensors

The National Imaging Story (so far)...

- **National Semiconductor is a leading supplier of advanced integrated circuits for digital imaging.**
- **Our mixed-signal technology can be found in scanners, digital still cameras, camcorders, PC cameras, copiers, and many other applications.**
- **Our vision is to bring cutting-edge innovation in imaging systems-on-a-chip to the consumer marketplace.**



In 1995, National Semiconductor introduced the industry's first completely integrated Analog Front End (AFE) for scanners, creating affordable, high image quality solutions.



In 1998, National followed up with the industry's first complete USB scanner-on-a-chip, combining all the functions of a flatbed scanner into a single IC.





In 1999 and 2000, National unleashed a line of high-speed Analog Front Ends with pixel-rate processing for digital still cameras, camcorders, and PC cameras.





National Semiconductor's latest imaging innovation, a family of CMOS Image Sensors, opens the door to new imaging systems-on-a-chip by providing superior image quality, lower power consumption, lower system cost, and unlimited possibilities for custom on-chip integration.



National Semiconductor

Analog Applications 3

Starting with the ADCs at the heart of every digital imaging system, National has expanded into several exploding segments of digital imaging:

Scanner AFEs

Scanners on a Chip

CCD Camera AFEs

CMOS Imagers

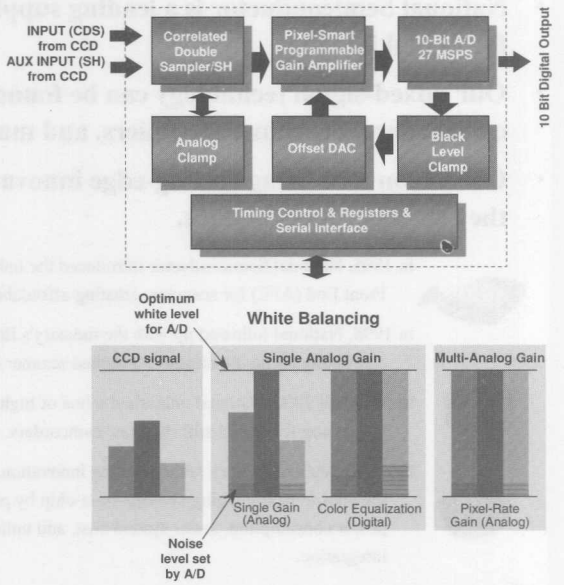
LM98501 Camera AFE

Specifications

27 MHz Correlated Double Sampler or Sample and Hold
0.0 to 32.0 dB Programmable Gain Amplifier
8bit Programmable Gain Amplifier
Low Noise Clamp Circuits
10 bit 27 MSPS Analog to Digital Converter
No Missing Codes
±0.5 LSB Differential Non-Linearity
SNR: 68 dB@0 dB Gain, 1.0 V
4 wire Serial Interface
+3.0 V Single Voltage Power Supply
Low Power: 195 mW @3.0V, 150 mW @2.7 V
48 LQFP package
0-70ºC Operating Temperature

Features

Pixel rate white balancing
Pixel rate offset elimination
Automatic black level compensation



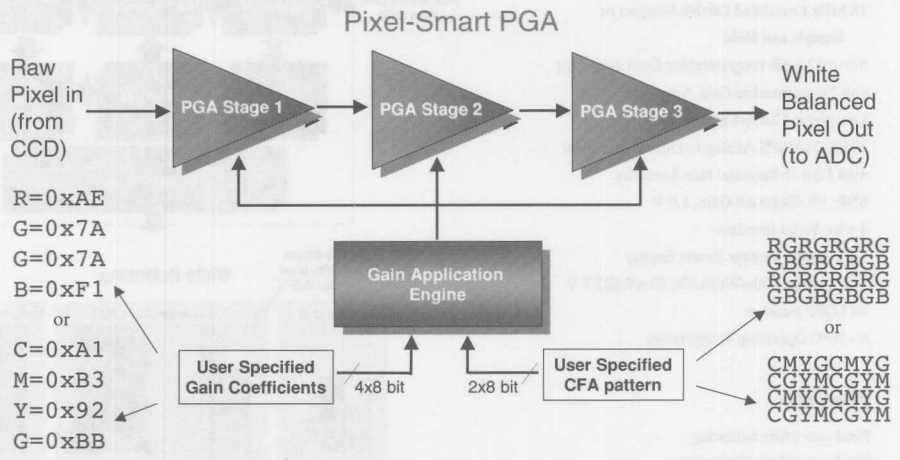
National Semiconductor

Analog Applications 4

Cameras need to be "white balanced" to make images look "correct" by compensating for the differing spectrum of various light sources (incandescent, fluorescent, sunlight, etc.), as well as the different sensitivities of CCD sensors to red, green, and blue light. White balancing is most often accomplished by applying different gains to the Red, Green, and Blue components so that a white image actually appears white. Most digital cameras do this by adding the maximum fixed analog gain possible to all three channels, typically limited by the green channel which has the highest sensitivity, and digitizing all three channels with that fixed gain. Once the image is digitized, the RGB components are multiplied by separate gains for R, G, and B in the digital domain, to bring them all up to full-scale, or "white". This works, but by applying the gain after the analog to digital conversion, you are actually amplifying the quantization noise of the ADC as well, reducing the quality of the image.

A better solution would be to change the gain before the ADC digitizes the video signal. If you can apply a separate gain for R, G, and B pixels, then each color can now use all the codes of the ADC, maximizing dynamic range and minimizing quantization noise.

Pixel-Rate White Balancing



Here's how the pixel-rate white balancing is implemented in National's camera AFE's.

Since the ADC receives the pixel information in sequential form (typically "RGRGRGRG…" for one line, "GBGBGBGBGB…" for the next), this requires that the PGA (Programmable Gain Amplifier) alternate between 2 different gains every pixel. 4 different 8-bit gains are loaded into the register (1 red, 1 green (for the "RGRGRG" line) , and 1 blue and 1 green (for the "GBGBGB" line). 2 different greens are used for maximum flexibility and to support alternate color patterns such as CMYG. 2 8-bit words are used to define the pattern.

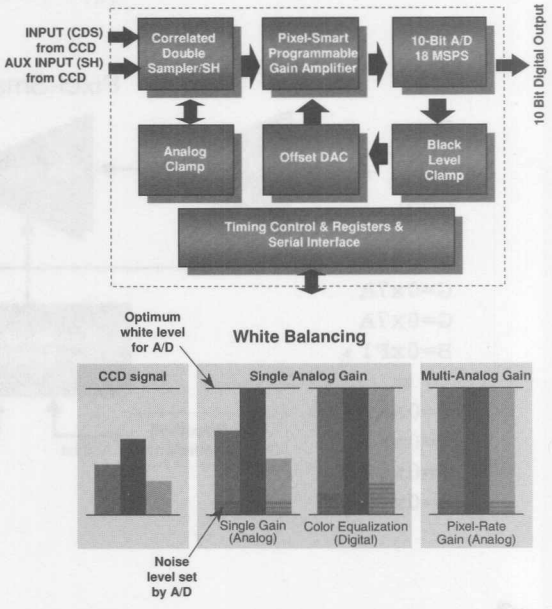
LM98503 Camera AFE

Specifications

18 MHz Correlated Double Sampler or
Sample and Hold
0.0 to 32.0 dB Programmable Gain Amplifier
8bit Programmable Gain Amplifier
Low Noise Clamp Circuits
10 bit 20 MSPS Analog to Digital Converter
±0.4 LSB Differential Non-Linearity
SNR: 68 dB@0 dB Gain, 1.0 V
4 wire Serial Interface
+3 V Single Voltage Power Supply
Low Power: 100mW@3.0V, 87mW@2.7 V
48 LQFP package
0 - 70°C Operating Temperature

Features

Pixel rate white balancing
Pixel rate offset elimination
Automatic Black level compensation



National Semiconductor

Analog Applications 6

The LM98503 is lower power, lower speed version of the LM98501, suitable for applications requiring pixel rates of 18MHz or less. But here's some more technical info for those of you reading the notes...

One thing to note about CCD pixels is that they generate charge even when no light shines on them. The amount of charge generated varies from CCD to CCD and over temperature. The amount of signal present when no light is shining is generally referred to as "black signal". On most CCDs, pixels at the end of each row are covered with metal so that no light can shine on them. The output of these pixels thus provides a "black reference" signal level.

One function of the LM9850X is to measure the output level of the CCD during these black pixels and to add an appropriate offset voltage to the channel to force this black signal level to a desired ADC output level (code 32 for instance). The process is as follows: At the beginning of each CCD line, when the black pixels are input to the LM9850X, the BLKCLP pin is set high. While it is high, the LM9850X measures the ADC output and adjusts the offset DAC in such a way as to move the ADC output code from the measured "black" value to code 32. The required DAC offset code is stored in an internal register and is updated each line as needed to maintain the ADC output at code 32 for black pixels.

When applying different gains to different pixels, the black reference level of each pixel is also multiplied by the different gains. This is illustrated in this slide which shows the original black reference level raised to 3 different heights after the application of the balanced gains.

What the LM9850X does to overcome this problem is to calculate a separate offset DAC value for each gain setting and to update these offset values every 3rd or 4th line, depending on whether there are 3 or 4 colors in the color filter array. Each color receives its own offset DAC value to cause the black signal level to be equal to code 32 with that color's gain applied to the PGA.

LM9617 Monochrome CMOS Image Sensor

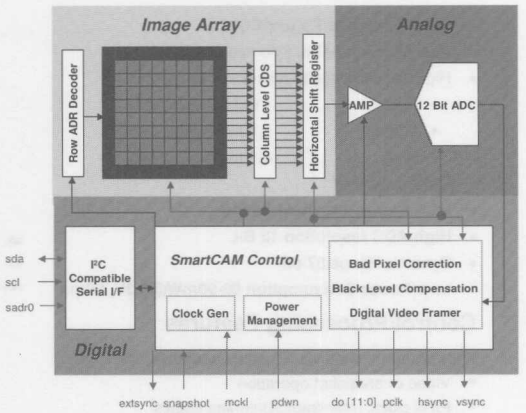
Analog Specifications

- Small Pixel Size 7.5 µmx7.5 µm
- High Fill Factor 47% (w/o microlens)
- **High Sensitivity**
 - 2.4V/(lux.sec)(monochrome, w/o microlenses)
 - 4.2 V/(lux.sec)(monochrome, w microlenses)
- Small Lens 1/3"
- **VGA Frame rate up to 30 fps**
- **High ADC resolution** 12 Bit
- Dynamic Range 57 dB
- **Low Power Consumption** 80-90mW@3.3V, 30fps

Control/Processing Features

Fully programmable via I²C serial interface:

- Video or snapshot operation
- Pixel clock, inter-frame&interline delays
- Partial or full frame integration
- Horizontal&vertical sub-sampling
- Windowing
- Analog Gain Adjustment
- Auto black level compensation
- Bad Pixel Correction



National Semiconductor

Analog Applications 7

LM9617 (monochrome) CMOS imaging chip is capable of capturing still or full-motion video images up to 30 frames per second and converting them to a digital datastream. The IC consumes just 90mW of active power at full frame rate when operating from a 3.3V supply, and 80mW when in a power management mode.

APPLICATIONS: Security Cameras, Barcode Scanning, Machine Vision, Motion Detection, Biometrics, etc.

The unique sensor core architecture attains a high fill factor resulting in a **very high sensitivity level up to 28.7kLSBs/(lux.sec)**. The LM9617 can significantly improve the performance of security cameras and machine vision at low light levels or in the IR-range while still operating at high speeds up to 30 frames per second. The high sensitivity, coupled with a high linear dynamic range of **60dB for the complete sensor response** and the **12-bit ADC resolution**, provides sharp, brilliant still and motion images in a variety of conditions.

The 12-bit datastream from the ADC can be reformatted into 8-bit or 10-bit datastreams, making it compatible with all currently available digital image processors. Moreover, a fully programmable on-chip timing and control system offers a very high level of design-in support. The timing and control system is programmable via an I²C-compatible interface. Programmable timing and control system functions are automatically synchronized, allowing the user for instance to set windows of any size and any position within the active array of the image sensor, and to zoom-in on a particular area of interest. Reducing window size also increases the frame rate.

Sub-sampling functions allow the user to preview the image with scaleable thumbnail scans. Two read-out modes - video and snapshot - can be used to control the datastream into the digital image processor. With full control of gain, exposure time and frame rate, users can tailor the sensor configuration according to their application needs and manage the sensors power consumption at different light levels.

LM9627 Color CMOS Image Sensor

Analog Specifications

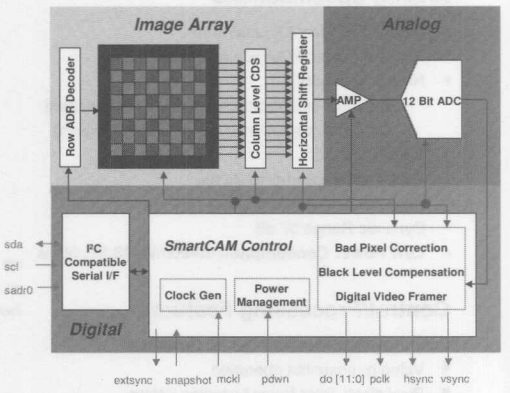
- Small Pixel Size 7.5 µmx7.5 µm
- High Fill Factor 47% (w/o microlens)
- High Sensitivity (with microlenses)
 - Red: 11 kLSBs/(lux.sec)
 - Green: 5.8 kLSBs/(lux.sec)
 - Blue: 4.1 kLSBs/(lux.sec)
- Small Lens 1/3"
- **VGA Frame rate up to 30 fps**
- **High ADC resolution 12 Bit**
- Dynamic Range 57 dB
- **Low Power Consumption 80-90mW@3.3V, 30fps**

Control/Processing Features

Fully programmable via I²C serial interface:

- Video or snapshot operation
- Pixel clock, inter-frame&interline delays
- Partial or full frame integration
- Horizontal&vertical sub-sampling
- Windowing
- Analog Gain Adjustment
- Auto black level compensation
- Bad Pixel Correction

National Semiconductor



Package Options

- **Production, LCC 9/00**
- Samples, CSP 10/00
- Production, CSP 4/01

LM9627 (color) CMOS imaging chip is capable of capturing still or full-motionvideo images up to **30 frames** per second and converting them to a digital datastream. The IC consumes **just 90mW** of active power at full frame rate when operating from a 3.3V supply, and **80mW when in a power management mode**.

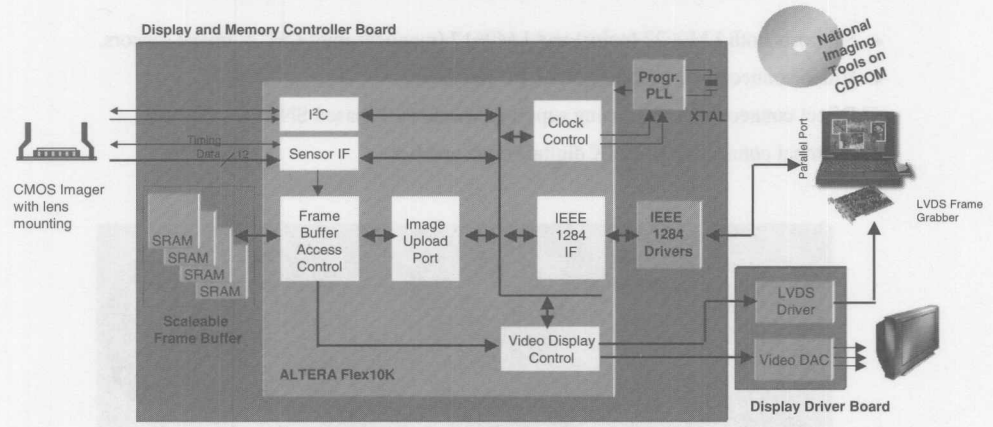
APPLICATIONS: PC and Dual Mode Cameras, Digital Still Cameras, Security Cameras, etc.

The unique sensor core architecture attains a high fill factor resulting in a **very high sensitivity level up to 11 kLSBs/(lux.sec)**. The high sensitivity, coupled with a high linear dynamic range of **60dB for the complete sensor response**, provide sharp, brilliant still and motion images under a variety of conditions.

The 12-bit datastream from the ADC can be reformatted into 8-bit or 10-bit datastreams, making it compatible with all currently available digital image processor. Moreover, a fully programmable on-chip timing and control system offers a very high level of design-in support. The timing and control system is programmable via an I2C interface. Programmable timing and control system functions are automatically synchronized, allowing the user for instance to set windows of any size and any position within the active array of the image sensor, and to zoom-in on particular area of interest. Reducing window size also increases the frame rate.

Sub-sampling functions allow the user to preview the image with scaleable thumbnail scans. Two read-out modes - video and snapshot - can be used to control the datastream into the digital image processor. With full control of gain, exposure time and frame rate, users can tailor the sensor configuration according to their application needs and manage the sensors power consumption at different light levels.

Imaging Evaluation System



Key Features

- Scaleable for SXGA, VGA, CIF, QCIF
- IEEE 1284 Interface with PC for system configuration and for downloading of raw data snapshots for further analysis and post processing (SW included)
- LVDS Interface to PC/Frame grabber for analysis of raw video and still images
- Video DAC to interface to CRT Monitor to display raw data video

National's imaging evaluation systems enable the user to perform a thorough evaluation of our CMOS image sensors through emulation of their application environment e.g. lighting characteristics, optics, register configurations, etc. It is a valuable tool in development and testing of image processing routines and algorithms for imaging systems such as a PC/dual mode cameras, machine vision systems, bar code scanners, security cameras, etc.

The imaging evaluation system is designed to help experienced camera engineers evaluate the raw performance of the imager/AFE. It is delivered as a complete plug-and-play kit including C-mount optics, power supply, software and all necessary cables. Immediately after connecting the evaluation kit to a PC and installing the included software, the evaluation kit is ready to deliver motion video data which can either be displayed directly on a computer monitor or captured for digital analysis.

The evaluation system as shown above consists of 3 boards and comes with software on a CDROM. The board also has an LVDS port, for use with an external LVDS frame grabber from Epix (not included!).

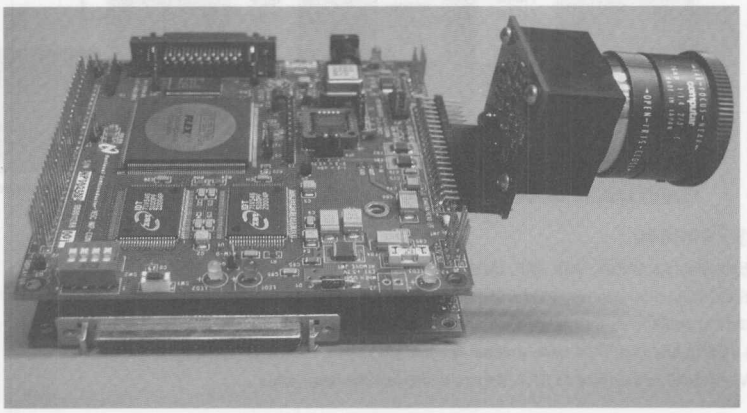
The included "Snaps" software package provides:

- Control of all registers inside the CMOS image sensor
- Upload of raw data from the CMOS image sensor to the PC
- Raw Data Analysis
- Color Processing

For engineers with less experience in camera/system design, National recommends using a complete reference design instead of this evaluation system. For availability of reference designs please contact Sunita Mathur (Imaging Marketing Manager) at 408-721-3702 or Sunita.Mathur@nsc.com.

LM96XX-EVAL Kit

- Supports both LM9627 (color) and LM9617 (monochrome) CMOS image sensors.
- Video connection to standard VGA PC monitor.
- Direct connection to PC (using supplied Windows™-based SNAPS software).
- Optional connection to EPIX digital frame grabber.



This is a photograph of the main evaluation board with attached headboard (on the right)

Ordering Options

LM9627EVAL-KIT

LM9627HEADBOARD
LM96XXCONTROLBOARD/LM96XXDISPLAYBOARD
SNAPS Software on CDROM
LENS
POWER CABLE
PARALLEL CABLE
POWER SUPPLY
LITERATURE PACKET

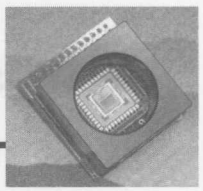


LM9617EVAL-KIT

LM9617HEADBOARD
LM96XXCONTROLBOARD/LM96XXDISPLAYBOARD
SNAPS Software on CDROM
LENS
POWER CABLE
PARALLEL CABLE
POWER SUPPLY
LITERATURE PACKET

LM9627HEADBOARD

LM9627HEADBOARD
LITERATURE PACKET



LM9617HEADBOARD

LM9617HEADBOARD
LITERATURE PACKET

The headboard is a small PCB holding the CMOS image sensor and all external components necessary to allow control of the sensor. The headboard interface is compatible with the evaluation kit's image sensor interface and thus allows the user to evaluate and test different sensors with the same evaluation kit. Alternatively, if you have already developed your own evaluation system or imaging product, the headboards could be easily integrated into your existing system.

If you're interested in any of our CMOS imaging products, please contact National's Americas Business Marketing group:

Jennifer Schmitt (847-517-5563, Jennifer.Schmitt@nsc.com), or

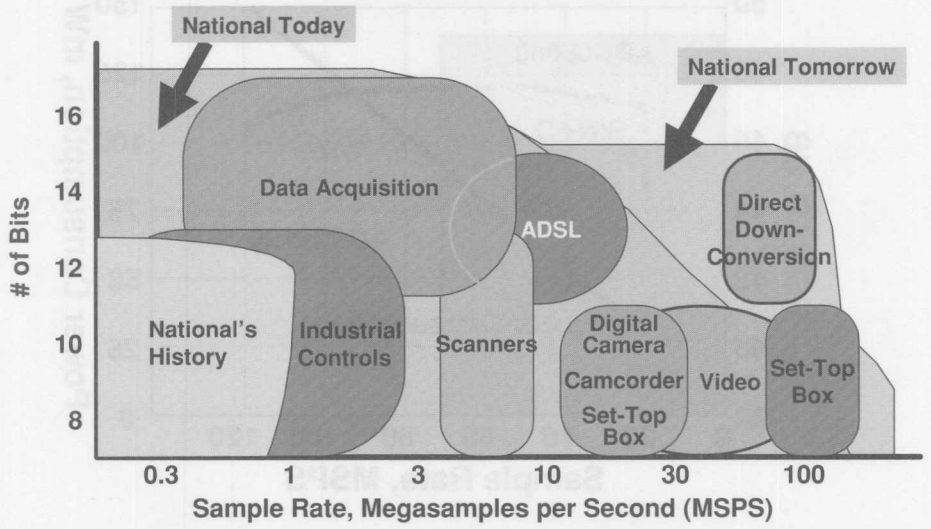
Mike Payne (847-517-5554, Mike.Payne@nsc.com)

ADCs at National Semiconductor

History

New Products

ADC Evolution at National



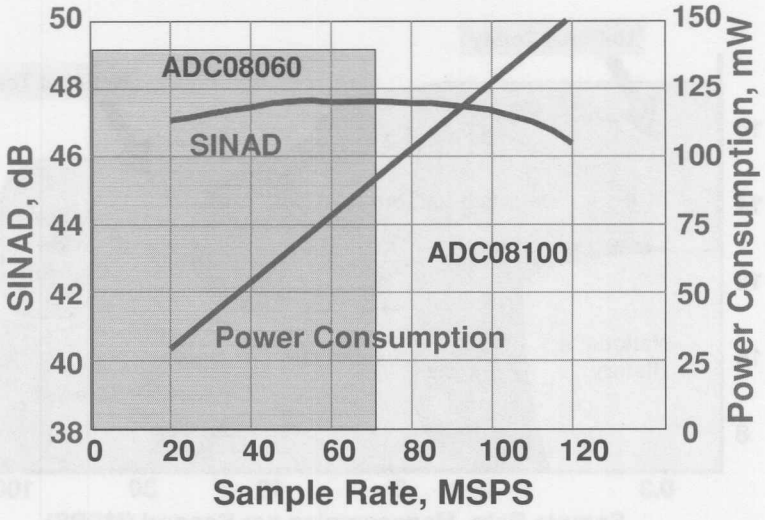
National Semiconductor

Analog Applications 13

In the 1980s, National was both an innovator and the number one supplier of 8 and 10 bit CMOS ADCs, primarily serving the industrial controls and automotive markets. National introduced the world's first half-flash 8 bit ADC, the ADC0820, in 1984. The ADC0820 combined near-flash speeds with near-SAR power consumption and cost, filling a large void in the ADC marketplace. The half-flash and multi-step architectures pioneered with this chip led to a series of faster and higher resolution ADCs throughout the 80s and early 90s.

In the mid-1990s, National started moving toward more vertically integrated system products in the PC and communications markets. Data converters played a large role in the cell phone, networking, IA, and PC peripheral products that National was introducing. This new direction for data converters took ADCs down a higher speed path. Where most of the ADCs introduced in the 80s and early 90s were sub-1MHz, National's latest 8, 10, and 12 bit ADCs now start at 40MHz and go up from there. With targets including cell phone base stations, image digitization, set-top boxes, and medical imaging, National's new ADC focus is orders of magnitude faster.

ADC08060/ADC08100



Sporting the best overall performance of any 8 bit 100MSPS ADC, the ADC08100 has a SINAD that is essentially flat over its 20MSPS to 120MSPS range of sample rates. Its power consumption is among the lowest its class, and its unique power scaling with sample rate means that there is no "power penalty" for using this ADC at less than its rated sample rate, as is the case with other ADCs.

ADC08100 (ADC08060)

8-Bit, 100MSPS (60MSPS)

Functional over 20 to 120MSPS (70MSPS) range

Power dissipation is 1.3mW/MSPS

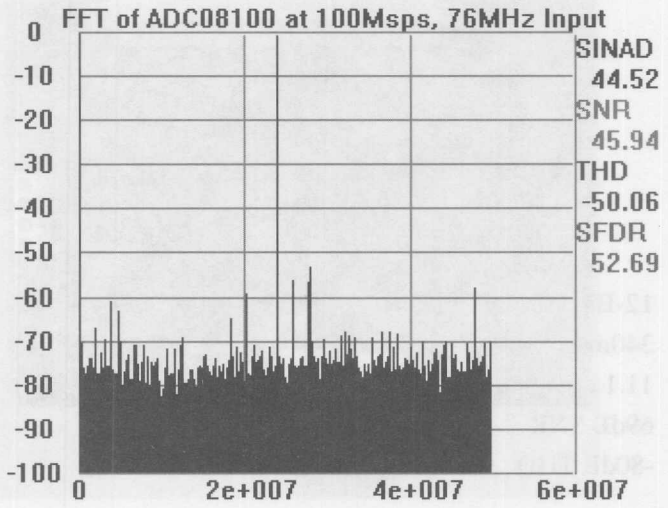
130mW@100MSPS

78mW @60MSPS,

26mW@20MSPS

ENOB:	7.5 typ, 7.0 (7.1) min
SNR	45dB typ, 40dB min (10MHz Input)
THD	-60dB typ (10MHz Input)
DNL:	0.4LSB typ
INL:	0.5LSB typ

ADC08100: Example of an 8-Bit ADC



The ADC08100 is a high speed, 8-bit converter specified for sampling at 100MSPS, but suitable for sample rates of 20MSPS to 120MSPS.

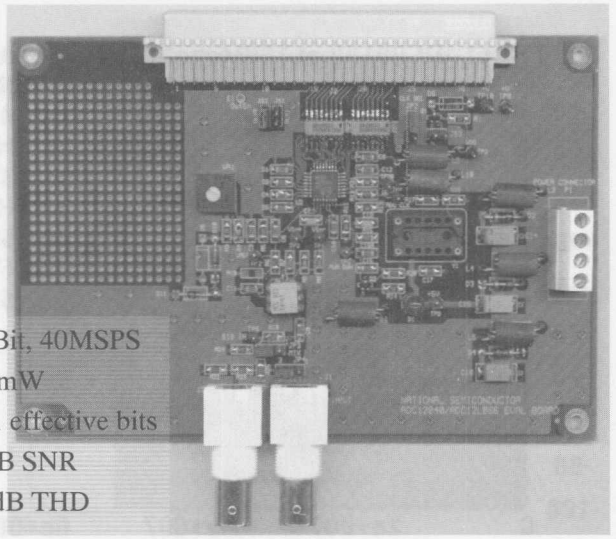
This frequency domain (FFT) plot was obtained with our ADC08100 evaluation system (with high speed data capture and PC interface) and proprietary WaveVision software. It gives insight into the performance of this ADC that goes beyond what you can get with just a datasheet or a "simple" evaluation system.

Our software is **free** and available from our web site at:

(http://www.national.com/appinfo/adc/files/wavevsn2.exe).

Note the excellent dynamic parameters at the top right of the plot. This is the superior performance achievable with the ADC08100, an 8-bit 100MSPS ADC. This performance is especially good when you realize that this is performance while undersampling a 76MHz input at 100MSPS.

ADC12040



- 12-Bit, 40MSPS
- 340mW
- 11.1 effective bits
- 69dB SNR
- -80dB THD

The ADC12040 is a 12-bit, 40MSPS ADC with applications in medical imaging and communications. Its 200MHz input bandwidth makes it suitable for both Nyquist and undersampling communications systems. The performance of this CMOS converter rivals that of even BiCMOS products, at a fraction of the power.

The photo above shows the WaveVision "Personality Board" for the ADC12040. This board can be purchased and used with a WaveVision capture board and software to fully evaluate the performance of the part without having to lift a soldering iron…

•12-Bit, 40MSPS

•0.1MSPS to 50MSPS Functional Range

•Power Consumption:

	Operating:	340mW typ
	Power Down:	1 mW typ

•ENOB: 11.1 typ

•SNR (10MHz Input): 69dB typ

•THD (10MHz Input): -80dB typ

(Tentative specifications - Product not released at press time)

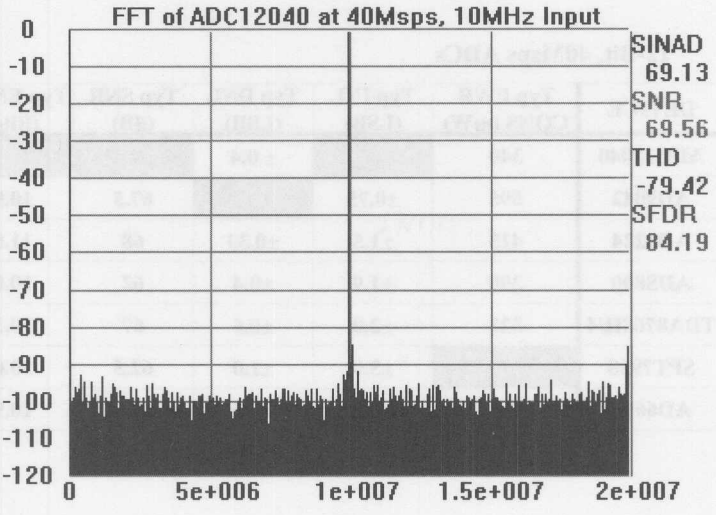
ADC12040 Competitive Stance

12-Bit, 40Msps ADCs

DEVICE	Typ PWR CONS (mW)	Typ INL (LSB)	Typ DNL (LSB)	Typ SNR (dB)	Typ ENOB (Bits)
ADC12040	340	±0.7	± 0.4	69	11.1
AD9042	595	±0.75	±0.3	67.5	10.9
AD9224	415	±1.5	±0.33	68	11.0
ADS800	390	±1.9	±0.4	62	10.8
TDA8768H/4	325	±2.0	±0.6	67	10.3
SPT7938	170	±3.0	±1.0	62.5	10.0
AD6640	710	±1.25	±0.5	67.7	10.9

The performance of this CMOS converter rivals that of even BiCMOS products, at half the power.

ADC12040 - Spectral Plot



This spectral plot of the ADC12040 shows the excellent performance of this device at 40MSPS with a 10MHz input. This low noise floor and excellent spurious performance is impressive, rivaling the performance of higher power BiCMOS products.

A faster, 3V version of this product is just over the horizon.

ADCV08832

- 8-bits, 153kHz sample rate
- 0.8 LSB max TUE (0.1 LSB typical)
- 1.7mW max power consumption (converting!)
- 100pA typical idle current
- MICROWIRE™ serial output (both MSB- and LSB-first)

The ADCV08832 is targeted for low power applications. This converter surpasses its competitors in terms of TUE (Total Unadjusted Error), sampling rate, and power consumption. The serial interface and size of this converter make it well suited for remote applications in noisy environments.

High Speed A/D Converter
8 and 10-Bit Selection Guide

DEVICE	RES (Bits)	SPEED (MSPS)	SUPPLY (V)	POWER CONS. (mW)	INL (LSB)	DNL (LSB)	ENOB (Bits)	SNR (dB)
ADC1173	8	15	3	40 (33 typ)	±1.3 (0.5)	± 0.85(0.4)	7.0 (7.6)	44 (48.7)
ADC1175	8	20	5	85 (60 typ)	± 1.3 (0.5)	± 0.75 (0.35)	7.0 (7.3)	44 (47)
ADC08351	8	42	3	48 (40.2 typ)	± 1.4 (0.7)	+1.3/-1.0(0.6)	6.1 (6.8)	41 (44)
ADC1175-50	8	50	5	190 (125 typ)	± 1.95 (0.8)	± 1.75 (0.7)	7.2 (6.7)	42.5 (46)
ADC08060	8	60	3	96 (76 typ)	± 1.3 (0.5)	+1.0/-0.9(0.4)	7.1 (7.6)	44.6 (47)
ADC08100	8	100	3	156 (126 typ)	± 1.3 (0.5)	+1.0/-0.95(0.4)	7.0 (7.5)	44 (47)
ADC10221	10	15	5	110 (98 typ)	± 1.0 (0.45)	± 0.85 (0.35)	9.0 (9.5)	58 (60)
ADC10321	10	20	5	110 (98 typ)	± 1.0 (0.45)	± 0.85 (0.35)	9.0 (9.5)	58 (60)
ADC10030	10	30	5	130 (121 typ)	± 1.0 (0.45)	± 0.95 (0.4)	8.6 (9.4)	54 (59)

We have high speed A/D Converters that fill a variety of needs and are adding more. Here is our current offering of 8- and 10-bit high speed (sample rates of 1MSPS and higher) ADCs. Of course, we still offer a variety of slower ADCs, but here we highlight our high speed line. Our higher resolution high speed ADCs are on the next page.

High Speed A/D Converter
12, 14, and 16-Bit Selection Guide

DEVICE	RES (Bits)	SPEED (MSPS)	SUPPLY (V)	POWER CONS. (mW)	INL (LSB)	DNL (LSB)	ENOB (Bits)	SNR (dB)
ADC12062	12	1	5	75 (60 typ)	- ± 1.5 (0.4)	± 0.95 (0.4)	11 (11.5)	69.5 (72)
ADC12662	12	1.5	5	200 (170 typ)	± 1.5 (0.4)	± 0.95 (0.4)	10.8 (11.3)	67.5 (70)
ADC12081	12	5	5	140 (105 typ)	± 1.7 (0.6)	± 0.75 (0.35)	10.4 (10.9)	65 (68)
ADC12181	12	10	5	290 (235 typ)	± 2.1 (0.7)	± 0.8 (0.4)	10 (10.4)	62 (65)
ADC12191	12	10	5	290 (235 typ)	± 2.3 (0.7)	± 0.95 (0.4)	- (10.4)	- (63)
ADC12281	12	20	5	530 (443 typ)	± 2.5 (1.0)	± 0.9 (0.35)	10 (10.5)	62.5 (65.5)
ADC12040*	12	40	5	395 (340 typ)	± 2.5 (0.7)	± 0.95 (0.4)	11.1 (11.3)	69 (72)
ADC14061	14	2.5	5	475 (390 typ)	± 2.5 (0.75)	± 1.0 (0.3)	- (12.8)	- (80)
ADC14161	14	2.5	5	475 (390 typ)	± 2.5 (0.75)	± 1.0 (0.3)	12.3 (12.8)	77 (80)
ADC14071	14	7	5	425 (380 typ)	- (2.2)	+1.0/-0.85 (0.6)	12 (12.6)	78 (80)
ADC16061	16	2.5	5	475 (390 typ)	± 9.0 (3.0)	+3/-2 (1)	- (12.8)	- (80)

** Specifications not final at preparation time. Planned introduction in February 2001*

While we do have a reasonable portfolio of high speed ADCs, that portfolio is growing. We are proud of the performance of our products and feel you will like what you see when you try any of them.

Let us know of your needs. We do not promise to produce everything that everyone requests, but your needs, combined with those of others, will tell us more about what is needed and we can better serve you, our customers.

Choosing the Right Temperature Sensor

Temp sensor overview

Tiny Temp Sensors

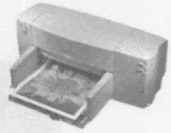
Design Considerations for PC

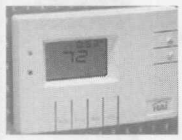
Thermal Management

National's Focus Areas for Temperature Sensors

- Multiple Remote Diode Temperature Sensors (RDTS) for PCs
 - LM87, LM83
- Tiny Temperature Sensors for Portable Systems
 - LM20, LM70, LM74
- Accurate Temperature Sensors
 - LM76, LM92









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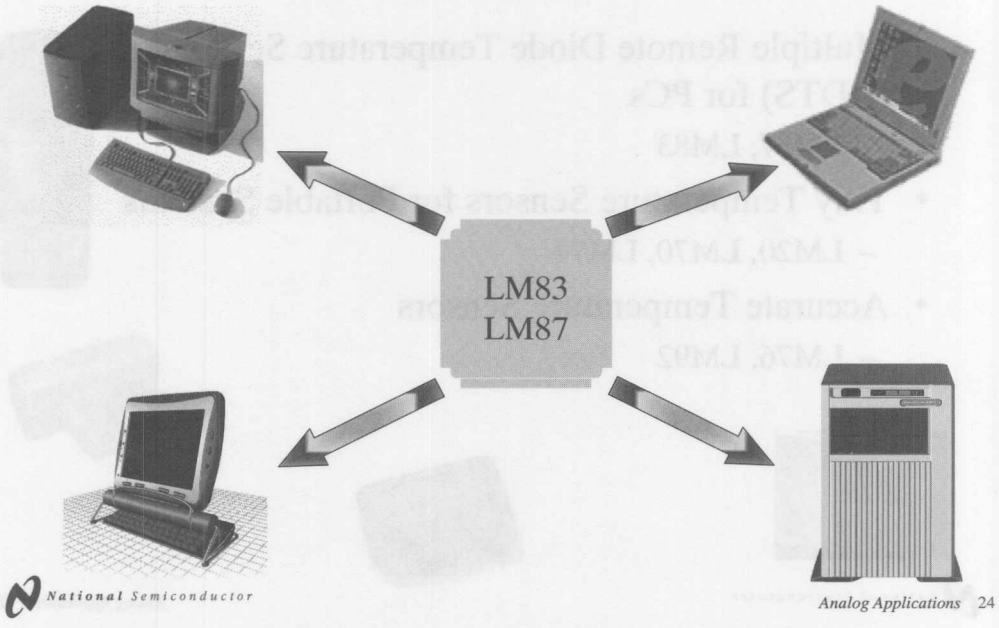
Analog Applications 23

National Semiconductor has a wide variety of integrated circuit temperature sensors for many different uses. Traditionally used in Heating Ventilation and Air Conditioning (HVAC) control systems, temp sensors can now be found in PCs, PC peripherals, cell phones, other communications equipment, and many other places. IC temperature sensors can measure the temperature of a printed circuit board, ambient air, chassis case temperature, and, most famously, the die temperature of a power-hungry ASIC or CPU. The latter is where remote diode temperature sensing (RDTS) has found a home. Sensing the case temperature of power hungry ICs has always had its mechanical challenges in terms of placement and mounting. If the IC is a surface mounted device it usually has hundreds of pins making it a PCB layout nightmare to position the external temperature sensor close enough to get an accurate, low-thermal lag measurement. National's RDTS products help solve these kinds of monitoring problems.

With the continued miniaturization of portable systems, National has led in the challenge of miniaturizing IC packages. We recently released analog as well as digital temperature sensors in micro SMD and LLP packages. The 4 pin micro SMD package is smaller than any available surface mount resistor!

Applications in modern HVAC and process control systems require great accuracy. Again, National is the leader with the most accurate digital output temperature sensor available today.

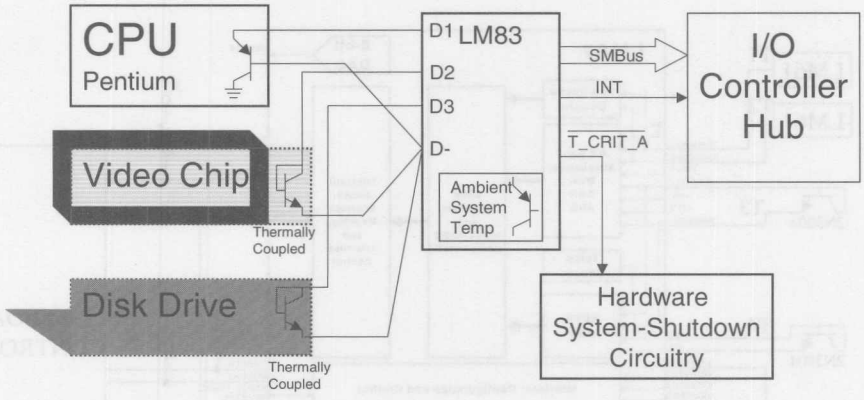
Multiple RDTS for PCs



The LM83 and LM87 are National's latest Multiple Remote Diode Temp Sensor (RDTS) products. A RDTS is a device that senses the temperature of a remote (to the RDTS) diode junction, using the diode's inherent temperature characteristic.

Remote Diode Temp Sensing was originally developed to sense the die temperature of today's high speed (and high-power) microprocessors, but our RDTS products can be used in any system where multiple temperatures need monitoring.

Three RDTS used in a PC



- *RDTS resolves placement issues*
- *2N3904 lower cost than thermistor or analog IC temp sensor*

The LM83 directly senses its own temperature and the temperature of three external PN junctions.

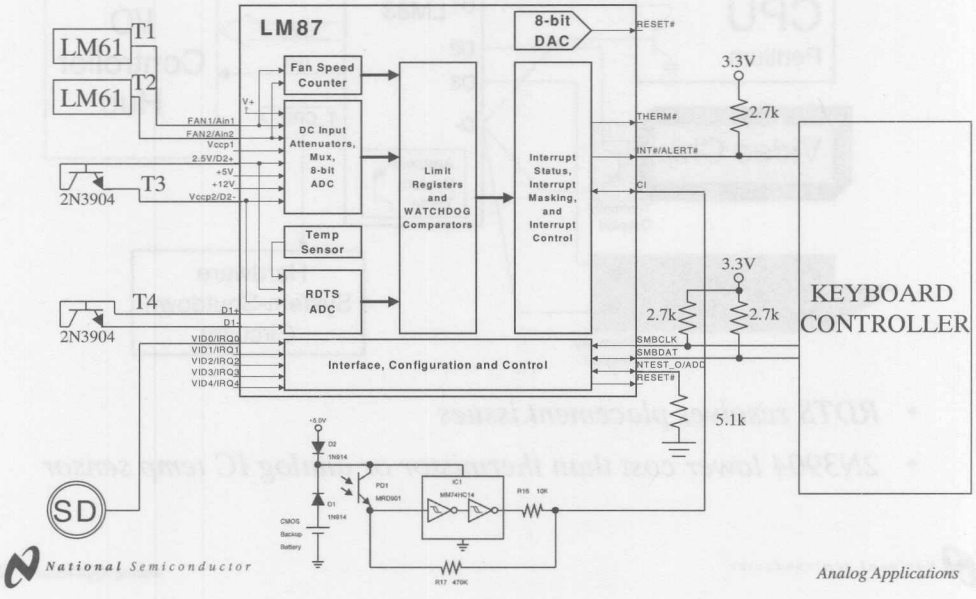
One input is dedicated to the CPU (whatever Intel flavor is in this month).

The other two can be dedicated to another part of your system that may have an overheating issue such as the disk drive. The LM83 is I^2C Bus and SMBus compatible, including SMBus timeout and logic levels.

Additional features include user-programmable limits, WATCHDOG capability with interrupt output, and a Critical Temperature Alarm output for system power supply shutdown.

Non-PC RDTS Application

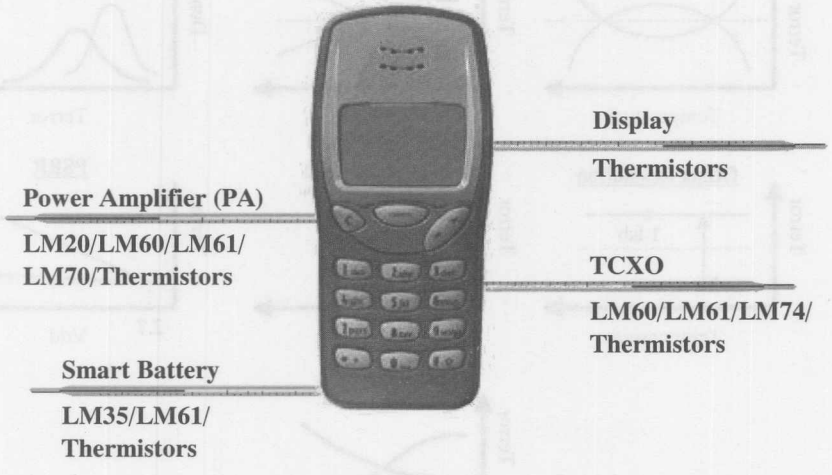
Intrusion Detection of an Automatic Teller Machine



National Semiconductor

Hardware monitors are used in many different systems where reliability and system down time are extremely critical. Originally, hardware monitors were targeted for the office PC, but recently they have gained wide acceptance in telecommunications (DSL, ADSL, routers) and banking systems. Here we show how the LM87 can be used in an ATM to detect a hostile chassis intrusion. Multiple temperature sensors located on PCBs as well as chassis mounted can be used to detect a heat source such as a blow torch. In this example four sensors are used, the two 2N3904 used as RDTS and two LM61 analog output temperature sensors. An IR detector is used to detect light. The LM87 is monitoring the 3.3V, 5V, and 12V power supply voltages of the system to determine if they are operating properly. A battery is used to power the LM87 so that it remains powered for several hours after the main supply voltage is disconnected. The alarm output of a smoke detector is routed to one of the IRQ (interrupt request) input pins of the LM87. When programmed as interrupt inputs a low on these pins (IRQ0-IRQ4) will cause the LM87 ALERT/INTERRUPT output to go low. The IRQ could be wire-ANDed with the ALERT/INTERRUPT output but doing so will not allow determination of which fault condition caused the interrupt. Routing the smoke detector interrupt through the LM87 allows the resolution of which fault condition caused the interrupt.

Tiny Sensors for Portable Systems



National's temperature sensors and hardware monitors are used throughout the cellular market. In a handset there are temperature sensors in:

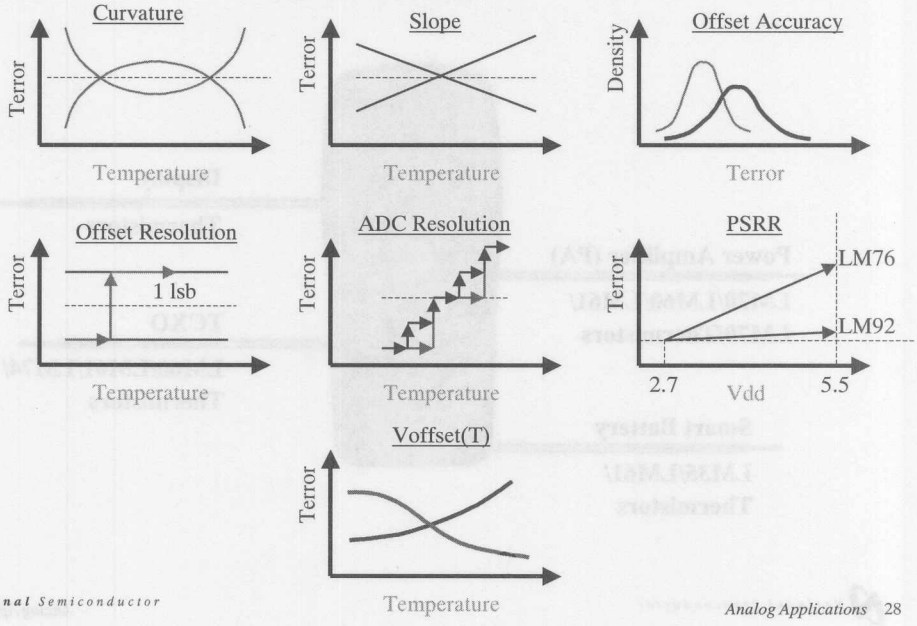
- The RF Power Amplifier for transmit power control
- The crystal oscillator for temperature compensation
- The battery charging, protection, and fuel gauging circuitry
- The display module for contrast control

Most cell phones use our lower-end digital or analog output temperature sensors, such as the LM20, LM45, LM50, LM60, LM61, LM70 and LM74. Base stations tend to favor our hardware monitors, such as the LM80 and LM81, for monitoring ambient temperature as well as the health of the power supplies and fans.

In systems where an ADC is already available, thermistors are popular because of their low cost. In our later session we will discuss the tradeoffs between thermistors and IC temperature sensors.

Improving Sensor Accuracy:

A Rogue's Gallery of Temperature Sensor Error Sources



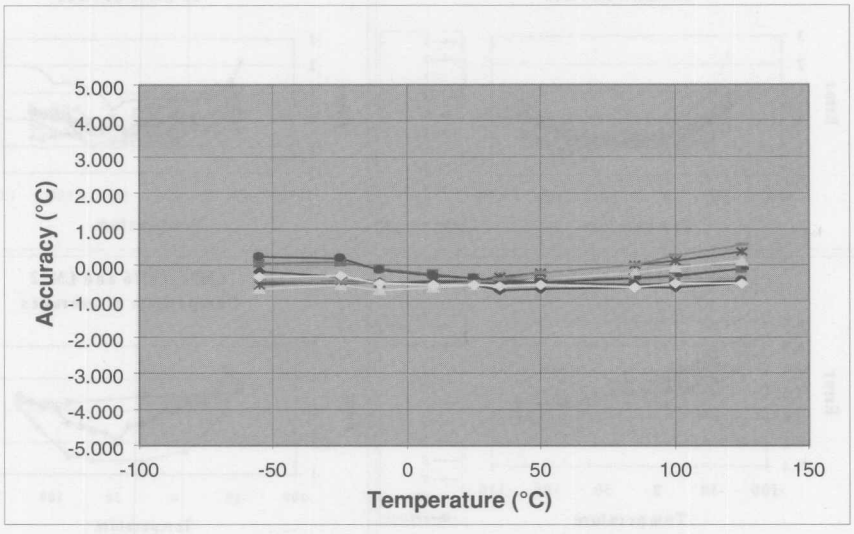
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Analog Applications 28

These are seven errors an engineer must consider when designing a temperature sensing system. National's silicon temp sensors compensate for or reduce these errors to levels you can live with.

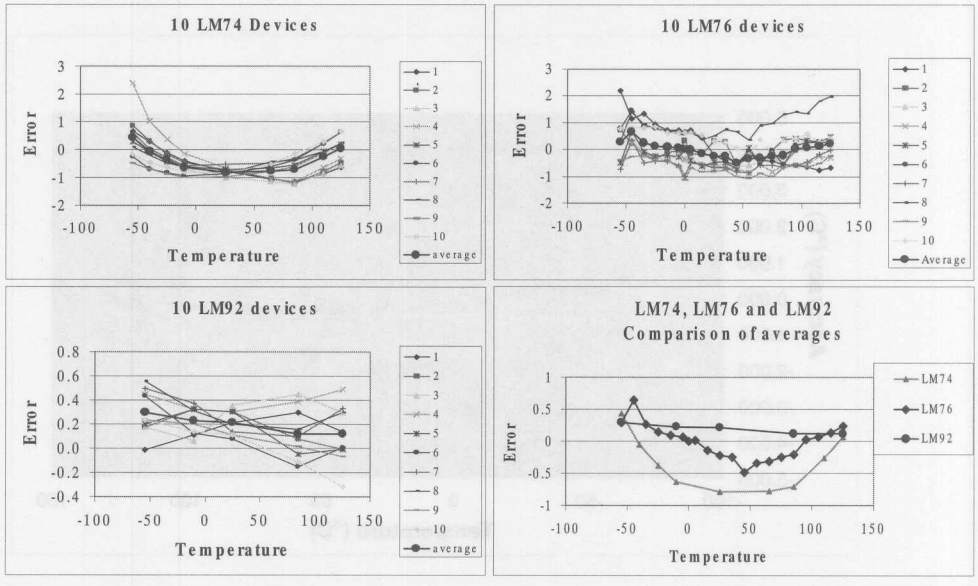
Improved Sensor Accuracy

LM92 Typical Performance Graph



The LM92 is our highest precision temp sensor. Note the extremely tight distribution of 8 typical units at room temperature, with accuracy still near ±0.5ºC at –55C and 125ºC.

Characterization Results Comparison



Until the introduction of the LM92 in March 2000, the LM74 (SPI and MICROWIRE™ interface) and LM76 (I^2C™ Interface) were National's highest precision temp sensors, and they're still suitable for most temperature sensing applications.

But for applications needing even greater accuracy, the precision LM92 is ideal. Guaranteed ±0.3ºC accurate at room temperature, and ±1.0ºC accurate from –10ºC to +85ºC, the LM92 is the most precise silicon temp sensor available on Earth.

MICROWIRE™ is a registered trademark of National Semiconductor Corporation

I^2C™ is a registered trademark of Philips Corporation

Tiny Temperature Sensors for Portable Systems

Tiny Packages

Thermistors versus ICs

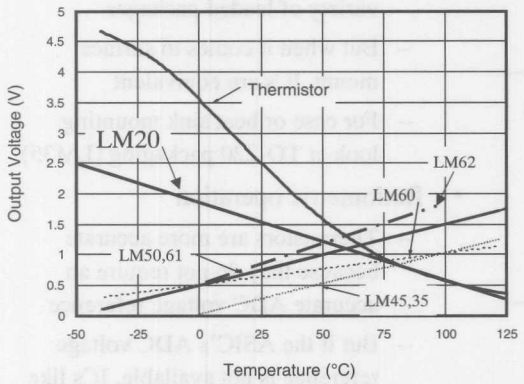
Tiny Package Temperature Sensor Summary

- 4-bump micro SMD: LM20*
- 5-bump micro SMD: LM74*
- 8-pin LLP: LM70*
- 5-lead SC70: LM20*
- 3-lead SOT-23: LM45, LM50, LM60, LM61, LM62
- 8-lead MSOP: LM75, LM70*

** Recently Released*

The LM20, LM45, LM50, LM60, LM61, and LM62 are analog output temperature sensors. They have various output voltage slopes (6.25mV/°C to 17mV/°C) and power supply voltage ranges (2.4V to 10V). The LM20 is the smallest, lowest power consumption analog output temperature sensor National Semiconductor has released. The LM70 and LM74 are MICROWIRE/SPI compatible digital temperature sensors. The LM70 has a resolution of 0.125°C while the LM74 has a resolution of 0.625°C. The LM74 is the most accurate of the two with an accuracy better than ±1.25°C. The LM75 is National's first digital output temperature sensor, released several years ago.

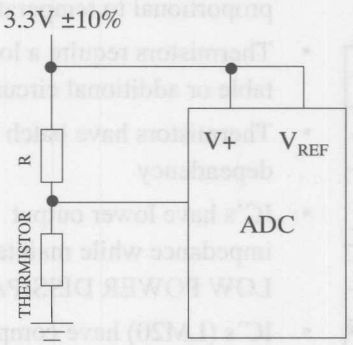
Thermistors versus ICs: Where ICs Win



- ICs have outputs linearly proportional to temperature
- Thermistors require a look-up table or additional circuitry
- Thermistors have batch to batch dependency
- IC's have lower output impedance while maintaining LOW POWER DISSIPATION
- IC's (LM20) have comparable cost
- IC's are easier to design with

These curves compare the temperature-to-voltage transfer functions of silicon temperature sensors with that of an NTC thermistor. Thermistor non-linearities can be corrected to some extent with lookup tables, but the inherent linearity of silicon sensors greatly simplifies system design.

Thermistors versus ICs: Where Thermistors Win

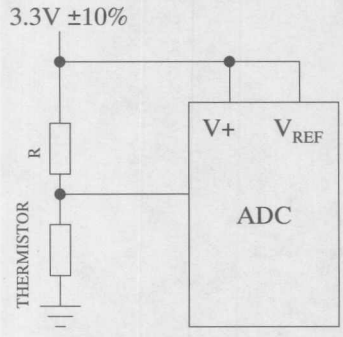


- Packaging Variety
 - Thermistors come in a wider variety of leaded packages
 - But when it comes to surface mount, ICs are equivalent
 - For case or heat sink mounting look at TO-220 packaging (LM35)
- Ratiometric operation
 - Thermistors are more accurate because they do not require an accurate ADC voltage reference
 - But if the ASIC's ADC voltage reference is not available, ICs like the LM20 are more accurate.

Thermistors come in a variety of packages ranging from probes to beads, beating ICs in that category. However ICs have surface mount packaging equivalent to thermistors, if not smaller as in the LM20 micro SMD.

Thermistors, when biased ratiometrically, have the advantage of not requiring an accurate or stable voltage reference in the system. In ratiometric operation, the error introduced by the reference is cancelled out. If ratiometric operation is not possible, for instance when the ADC reference voltage is in an ASIC and is not pinned out, using ICs like the LM20 will result in better total system accuracy.

Specific Analysis Using a Murata NTH5G10P/16P33B103F



- Accuracy of the Murata thermistor - 1% at 25°C
- Overall accuracy depends on:
 - resolution of ADC
 - errors of ADC (gain, offset and linearity, sometimes combined and called Total Unadjusted Error or TUE)
 - resolution of the compensation table
- Signal level falls off logarithmically
- Power dissipation dependent upon R

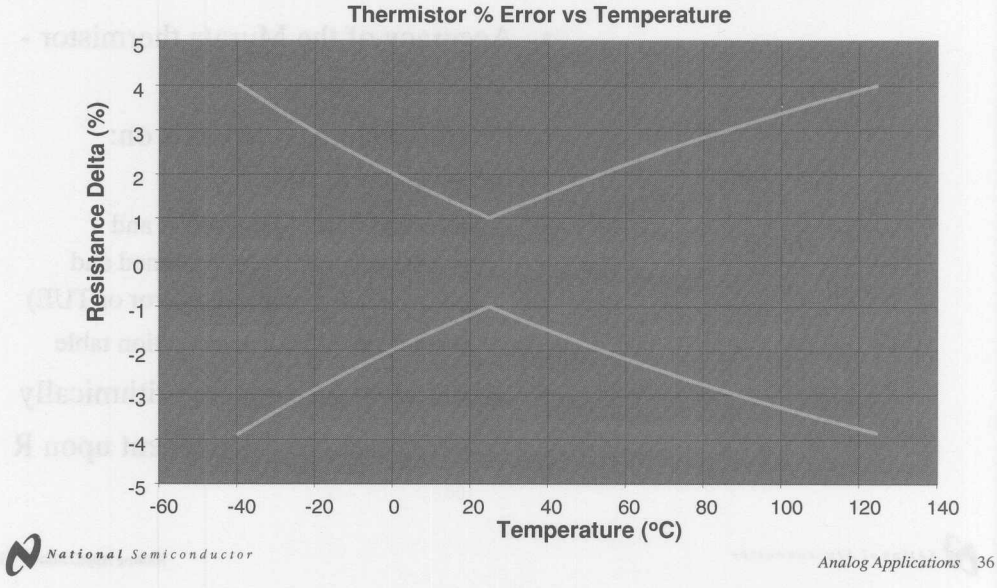
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Analog Applications 35

We analyzed a specific thermistor, the Murata NTH5G10P/16P33B103F. This thermistor has an accuracy of 1% at 25°C. The evaluation used ADCs with various resolutions to examine the effects of quantization error on temperature accuracy.

Some thermistors have been known to have a batch dependency.

Accuracy Spec Found on the Murata Thermistor Data Sheet

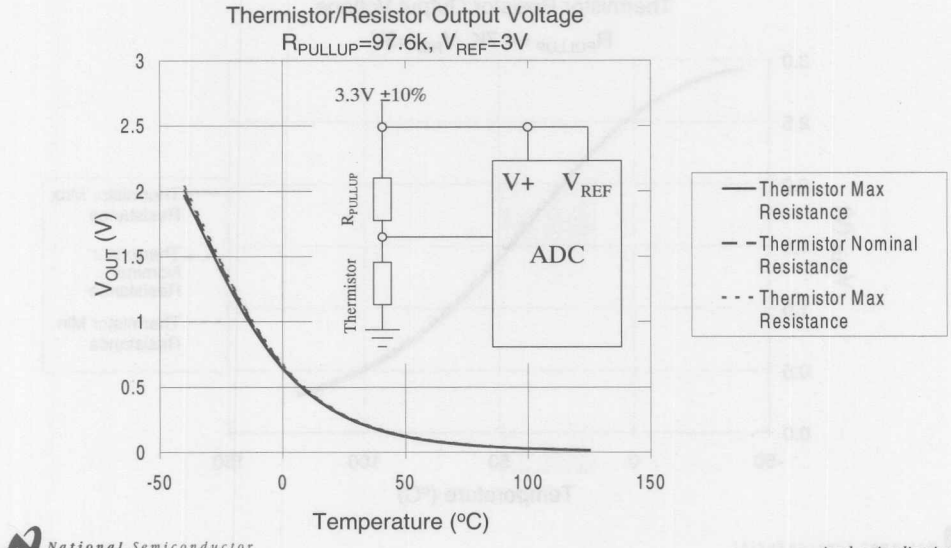


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Analog Applications 36

This is a plot of thermistor resistance accuracy versus temperature.

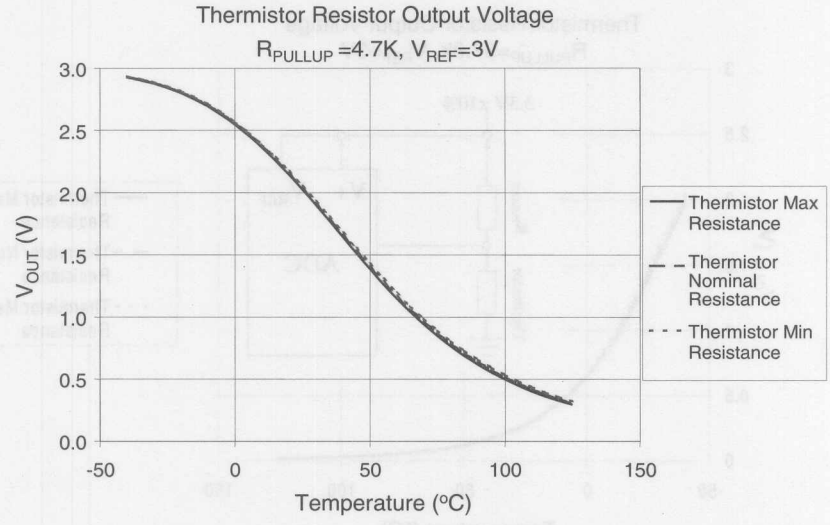
Thermistor Circuit Transfer Function with R=97.6k



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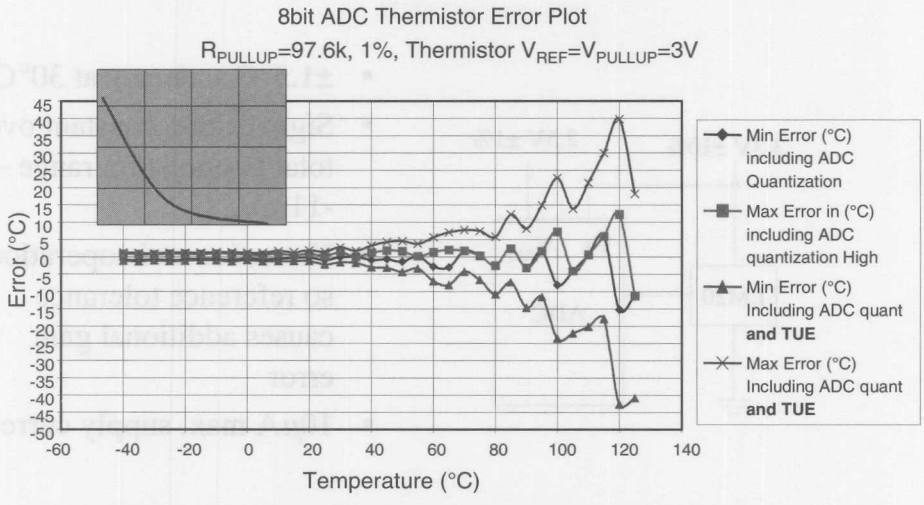
Here's a plot of the voltage generated by the resistor/thermistor divider and applied to the ADC input. Note that the ADC input voltage decreases logarithmically with increasing temperature. The 97.6k resistor minimizes the power dissipation in the thermistor, keeping the thermistor from exceeding it's maximum power rating and thus maintaining the thermistor's specified accuracy.

Thermistor Circuit Transfer Function with R=4.7k



Lowering the value of the resistor from the previous slide will lower the temperature range over which the thermistor's transfer function is linear. With a 4.7k bias resistor, the slope increases at higher temperatures, providing more resolution. However this improvement comes with a price: greater power consumption in the overall circuit, and self-heating in the thermistor itself, causing elevated temperature readings (in this case about 0.2-0.3º C).

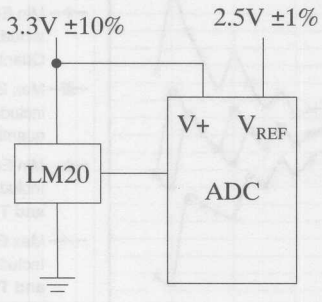
Thermistor Accuracy Including ADC Errors



30µA thermistor bias current

This plot shows the overall system accuracy when using an 8-bit ADC. In a real world application, the quantization error and ADC Total Unadjusted Error must be considered to determine the overall system error. Note how quickly the temperature error due to the ADC's TUE and quantization error start to increase above room temperature.

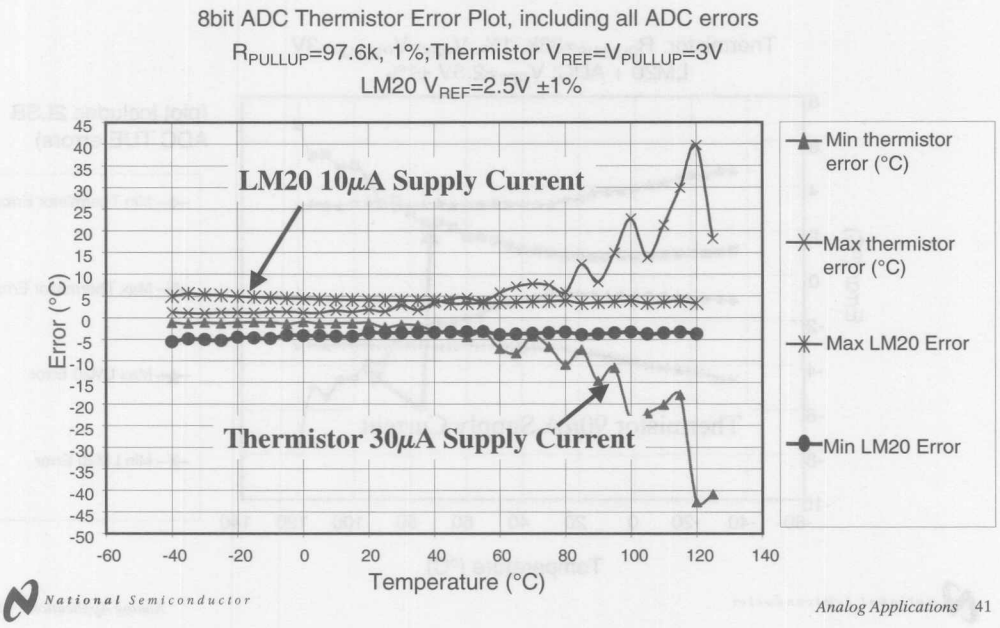
Specific Analysis Using an LM20



- ±1.5°C accuracy at 30°C
- Signal slope constant over total temperature range ~ -11mV/°C
- Not ratiometric operation, so reference tolerance causes additional gain error
- 10μA max. supply current

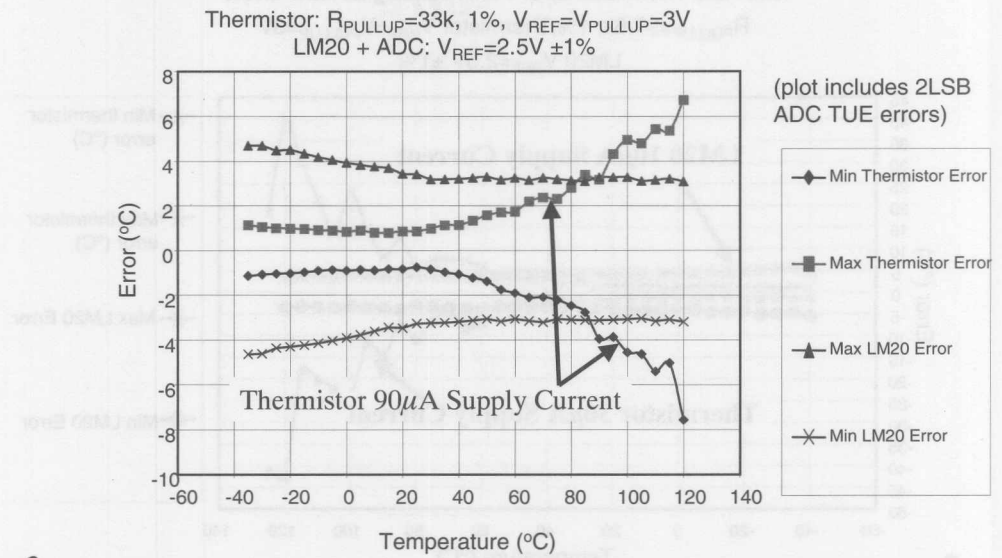
Now let's compare an LM20 system using the same 8-bit ADC and a reference voltage with 1% accuracy. Since this is not ratiometric operation, the reference adds additional system error.

LM20 vs Thermistor (8-bit ADC)



In this graph the LM20's performance is compared to a thermistor with an 8 bit ADC. Overall system accuracy for the LM20 remains constant over temperature. At temperatures above 60°C, the LM20 wins big!

LM20 vs Thermistor (10-bit ADC)



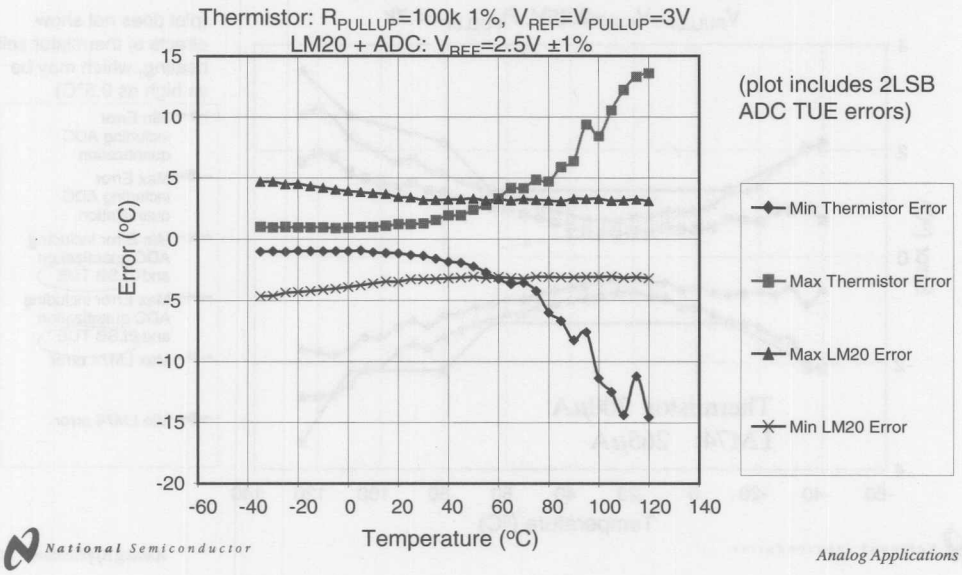
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Analog Applications 42

As the ADC resolution is increased, the overall system error decreases because the ADC's quantization error decreases. The thermistor benefits the most because it is running ratiometrically while the LM20 is not, so the reference voltage error dominates over the improved accuracy of the ADC. Improving the accuracy of the voltage reference will bring the LM20 system accuracy closer to that of the specifications found on the LM20 data sheet of ±2.5°C at +130°C and -55°C, and ±1.5°C at +30°C. Since the output slope of the LM20 is negative the gain error introduced by the reference voltage plays less of a role in the overall accuracy as the temperature increases.

LM20 vs Thermistor (10-bit ADC)

When Supply Current Matters



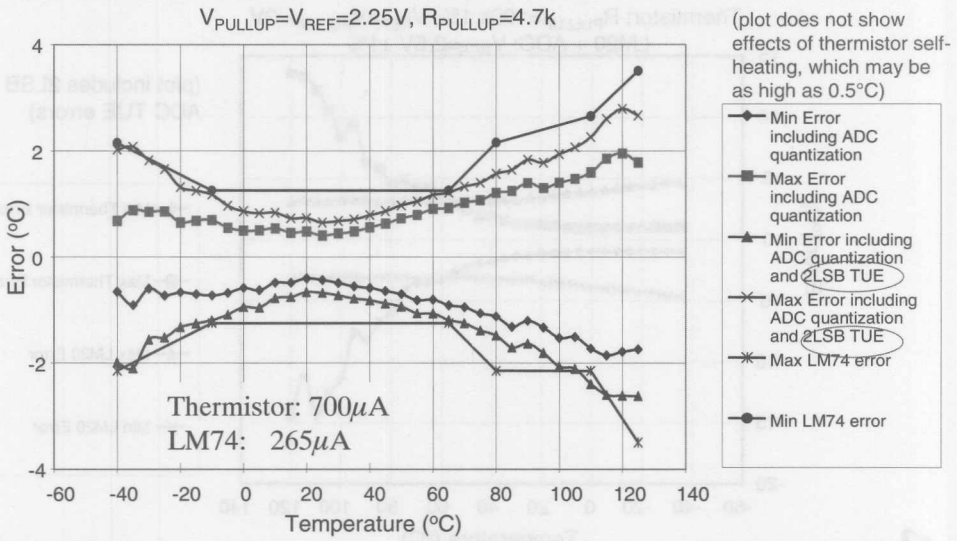
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Analog Applications 43

But if you want to reduce the power consumption of your thermistor source to 30μA (still 3x higher than the LM20), the thermistor performance becomes worse at about +60°C.

LM74 (Digital Temp Sensor) vs Thermistor with 10-bit ADC

When Supply Current Doesn't Matter



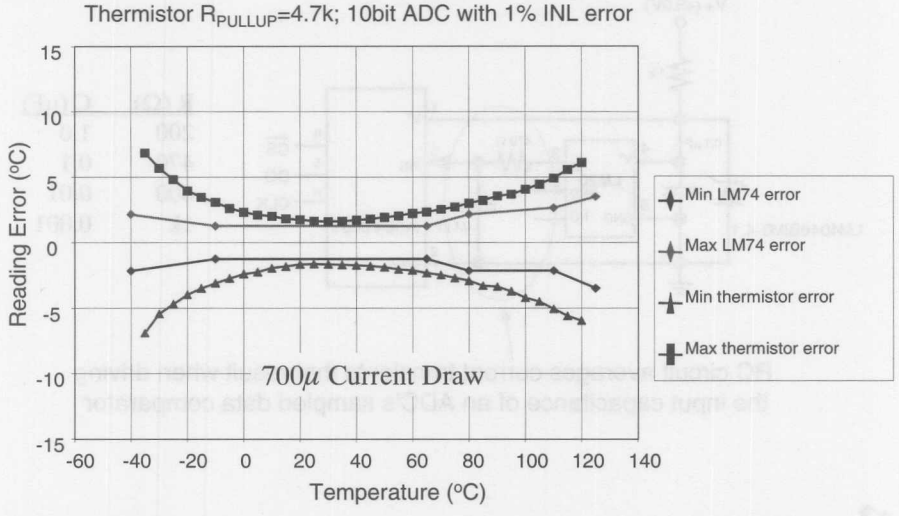
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Here is a curve of the LM74 when compared to a thermistor and a 10-bit ADC. Here the pullup resistor has been lowered to 4.7k thus increasing thermistor accuracy at the cost of power dissipation. At first it may appear that the thermistor provides better performance than the LM74 but the thermistor error plots do not include the self heating error of the thermistor which can be as high as 0.5°C.

The LM74 comes in two flavors, the LM74-3, optimized for 3V power supplies, and the LM74-5, optimized for 5V.

LM74 vs Thermistor with 10-bit ADC

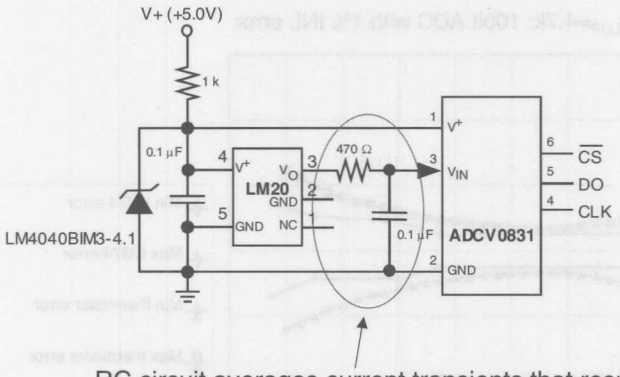
When using an ASIC watch out for the ADC TUE!



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This plot shows how the performance of the thermistor is degraded when using an ASIC that has a 10-bit ADC with an overall DC accuracy of 1%. This is the case with many ASICs that have an imbedded ADC intended for use in digitizing high speed AC signals. They usually have excellent AC performance specifications (THD, SNR, ...), but lackluster DC performance (TUE, GAIN, OFFSET, INL). DC performance is what matters when digitizing a thermistor. Don't be fooled by the resolution of the ADC - check out its DC performance.

LM20 Driving ADC Inputs



R (Ω)	C (µF)
200	1.0
470	0.1
600	0.01
1k	0.001

RC circuit averages current transients that result when driving the input capacitance of an ADC's sampled data comparator

The LM20 has a 10μA maximum supply current rating. In order to minimize the supply current, the output buffer in the LM20 has a very low bandwidth. When driving ADCs with sampled data comparator inputs, such as the ADCV0831 and those found on most CMOS ASICs, there is a requirement that the signal source provide a large peak current at the time of sampling. The LM20 output cannot provide this current and settle its output voltage in the time before the ADC acquisition window ends. The solution is the addition of a 0.1uF reservoir capacitor to store charge and provide the necessary current required at the time the ADC samples the analog input. This eases the requirements on the LM20's output stage. The LM20 needs only to charge the capacitor back up to the proper voltage before another sample is taken. If the ADC samples again before the capacitor is recharged, an error voltage will be induced. The value of the capacitor should be empirically derived since the capacitance of the ADC's input stage at time of sampling varies greatly from one ADC manufacturer to another.

When Should You Use IC Temperature Sensors?

- When the sensor's temperature range will be between -55°C and +150°C
 - Electronic Systems Monitoring
 - Environmental Controls and Measurements
- When system cost is important
- When design time must be minimized
- When space is at a premium
- When low supply current is a requirement

Designers have numerous options for temperature sensing techniques. Thermistors, RTDs, thermocouples, and active silicon sensors are among the most common, and each has its own set of advantages and disadvantages in any application. IC sensors have major advantages when the temperatures to be measured fall within the normal operating temperature range of silicon ICs. Among these advantages are low system cost, small size, and fast design time (because external signal conditioning circuitry is either minimal or not required). In addition, sensor ICs can include extensive additional functions, such as built-in comparator trip-points or digital I/O. And, since they include on-chip linearity correction when needed, there is no need for lookup tables to correct linearity errors.

Design Considerations for PC Thermal Management

Multipoint Remote Diode Temperature Sensing (RDTS)

IC Topology

Performance in Noisy Environments

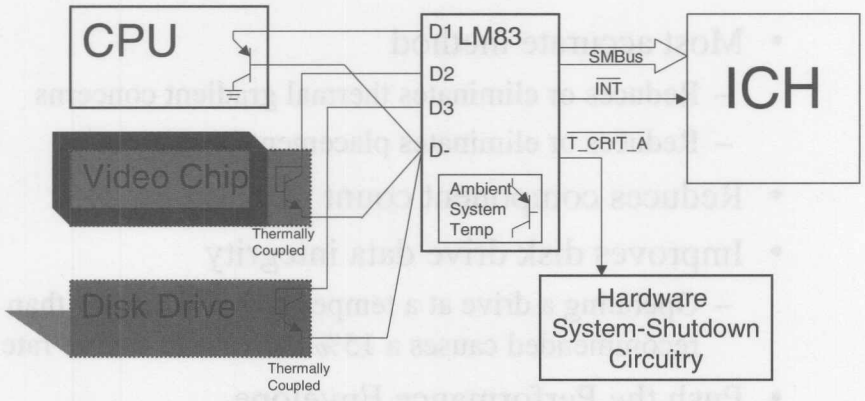
Why Use Multipoint Remote Diode Temperature Sensing (RDTS)?

- Most accurate method
 - Reduces or eliminates thermal gradient concerns
 - Reduces or eliminates placement issues
- Reduces component count
- Improves disk drive data integrity
 - Operating a drive at a temperature 5°C higher than recommended causes a 15% increase in failure rate
- Push the Performance Envelope
 - RDTS can lower a ±8°C error to ±3°C, so you can clock your system faster

Multiple RDTS (remote diode temperature sensing) provides the most accurate method of sensing an IC's junction temperature. It overcomes thermal gradient and placement issues encountered when trying to place external sensors. PCB component count decreases when using a device that provides multiple inputs.

Better temperature sensing improves product performance and reliability. Disk drive data integrity suffers at elevated temperatures. IBM published an article stating that a 5°C rise in operating temperature causes a 15% increase in the drive's failure rate. The overall performance of a system can be improved by providing a more accurate temperature measurement of the most critical devices allowing them to run just a few degrees hotter.

Typical Application

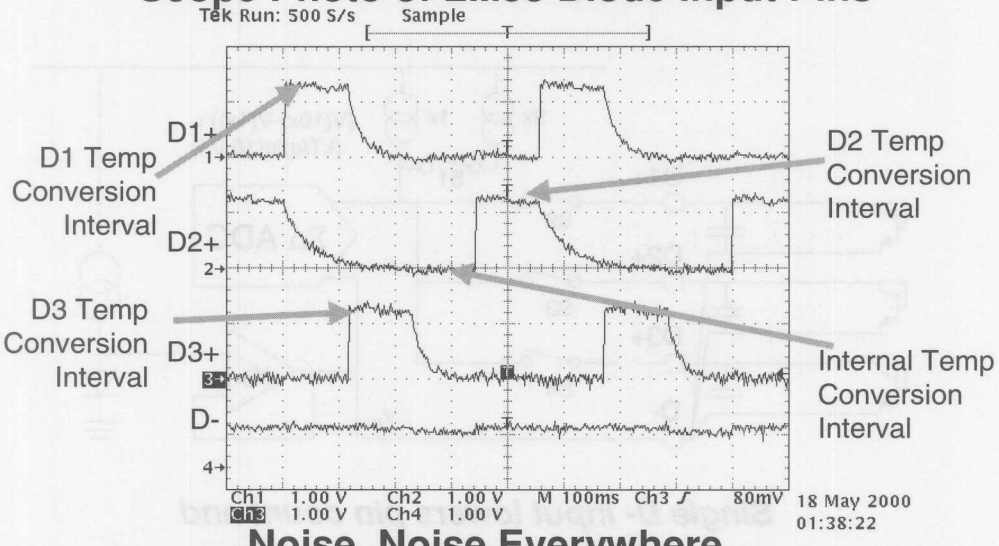


- *RDTS resolves sensor placement issues*
- *2N3904 lower $ than Thermistor or Analog Temp Sensor*

The LM83 directly senses its own temperature and the temperature of three external PN junctions. One is dedicated to the CPU of choice, the other two go to other parts of your system that need thermal monitoring such as the disk drive or graphics chip. The SMBus-compatible LM83 supports SMBus timeout and logic levels. The LM83 has two interrupt outputs; one for user-programmable limits and WATCHDOG capability (INT), the other is a Critical Temperature Alarm output (T_CRIT_A) for system power supply shutdown.

Performance w/ Noise

Scope Photo of LM83 Diode Input Pins



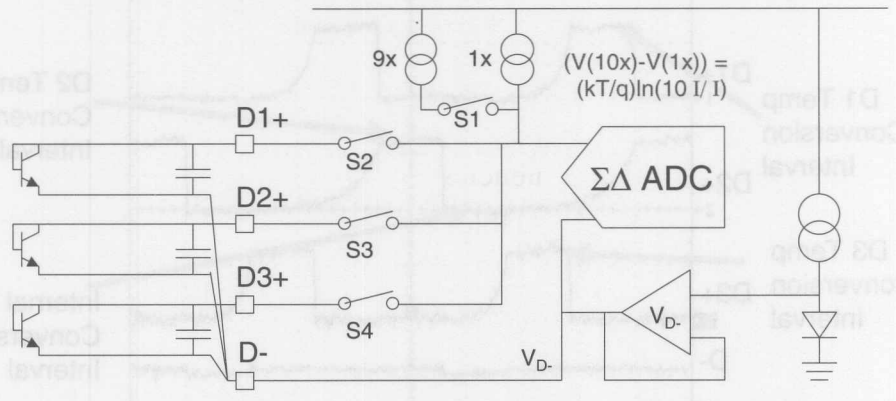
Noise, Noise Everywhere ...

How can an RDTS Resolve 100µV/°C signals?

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Noise, noise everywhere…let's look at what's actually going on here. The LM83 is sequentially sampling each input. Each diode is biased on at a different point in time. The pedestals in the top three waveforms are the time interval when that particular RDTS input is being monitored. When all three diode inputs are at zero, the internal diode is being sampled. Notice that the noise doesn't change much from channel to channel. See how stable the D- input is. There is only a a delta when going from and to an internal measurement. The slight change in the diode pedestal level is caused by the 10x and 1x current change during the diode measurement. This delta in DC voltage caused by the 10x to 1x current switching is not noticeable on the D- input. Why? Turn to the next slide…

IC Topology



Single D- input lowers pin count and reduces Total Cost of Ownership!

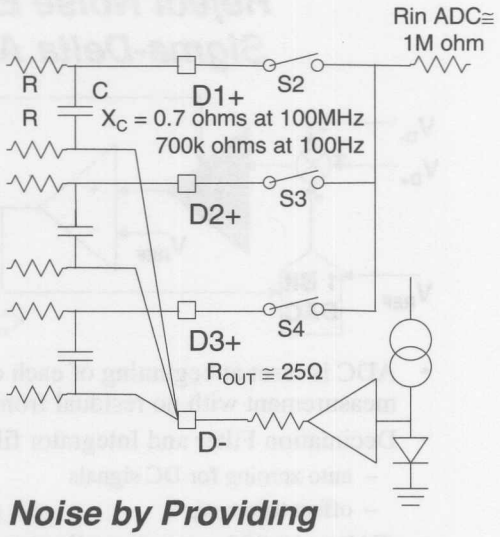
Without sacrificing noise performance, the LM83 allows multiple diode inputs to share a single D- input pin. This architecture maximizes the number of remote diode inputs the part can have. The D- "input" is forced to 0.7V by the VD- amplifier. This amplifier ensures that the D- input is a very low impedance node.

Note the capacitors on each channel's input. These capacitor's low impedance at high frequencies ensures that any high frequency noise injected on a D- or D+ input appears as a common mode signal to the ADC. The ADC differentially samples the D+ and D- pins, therefore any common mode signal will be rejected to the CMRR of the ADC. The low impedance output of the VD- amplifier, in conjunction with the external filtering capacitors, limit the amount of noise that is injected.

In operation, a sample is taken with 10x current forced through the diode under test. The 9x current is then switched off and a differential measurement is taken with the 1x current. The difference between these two measurements is proportional to temperature as shown in the equation above. To cancel out any low frequency noise signals that do not appear as common mode signal, 10,000 samples are taken and averaged by the ADC.

IC Topology

- Inherent impedance mismatch between D+ and D- *could* reduce differential noise rejection…
- But external capacitors short D+ to D- at high frequencies
- And opamp provides stable D- impedance at low frequencies, and as device switches between I and 10I

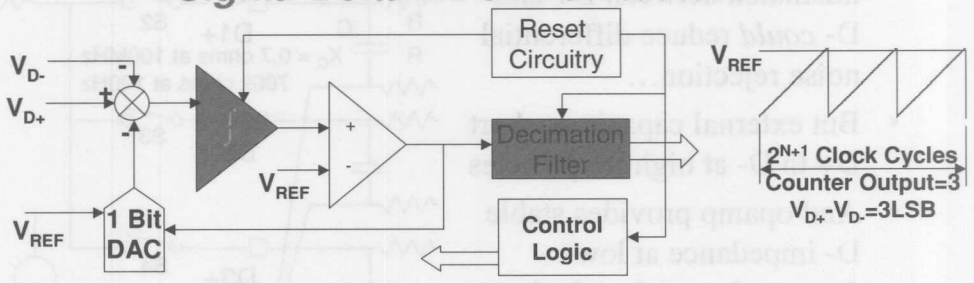


Op Amp Stabilizes Noise by Providing Similar D- Impedance for I and 10I measurements.

The D- input has a very low input impedance, while the D+ input impedance is very high. At high frequencies, this impedance mismatch is compensated for by the capacitors between the D+ and D- inputs. Since the capacitor's impedance is inversely proportional to frequency, they effectively short the D+ and D- inputs at high frequencies, forcing any high frequency noise on all the input pins to be identical. At low frequencies, trying to match the noise coupling on D+ and D- inputs is futile. The low impedance output of the VD- amplifier on the D- input forces the noise on all the D- lines to be equivalent and limits the amount of external noise that can be coupled in. Noise coupling between channels on the D- input, therefore, is minimal. The best way to cancel out low frequency noise error is internal filtering, as used in the LM83. Another alternative is to increase the external filter capacitor value, but this will limit the switching speed of the diode biasing current and increase the conversion time, slowing the overall system response time.

IC Topology

Reject Noise Even Further with Sigma-Delta ADC Architecture!



- ADC is reset at beginning of each conversion, providing accurate DC measurement with no residual from previous conversion
- Decimation Filter and Integrator filter noise and allow:
 - auto zeroing for DC signals
 - offset trimming
- ΣΔ's > 10,000x over-sampling/averaging provides much better noise rejection than SAR architectures

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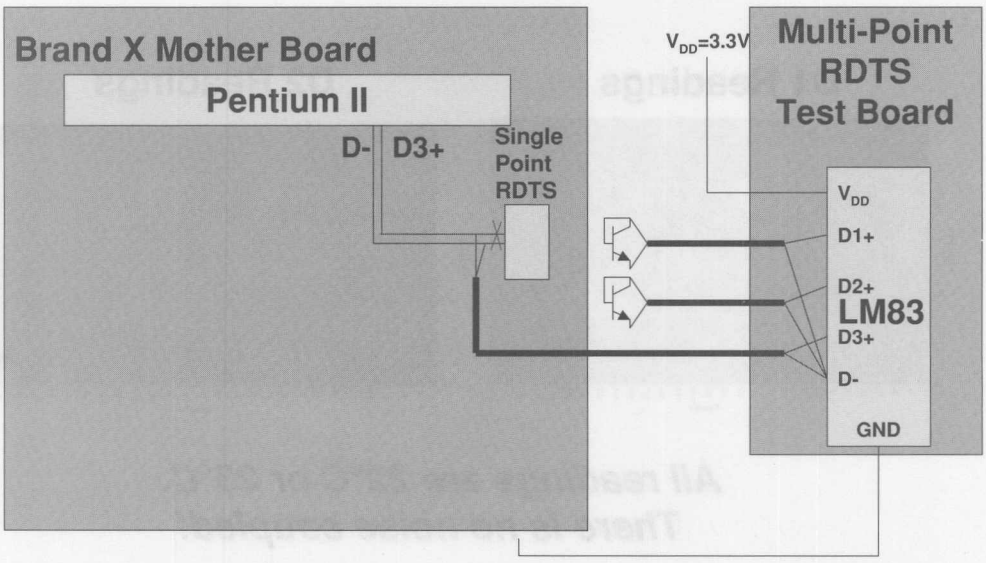
Analog Applications 54

The Sigma-Delta (ΣΔ) ADC used in National's temp sensors is a special architecture designed for DC and very low frequency inputs. While some traditional ΣΔ ADC architectures have problems with DC inputs due to tone generation at certain frequencies (the tone frequency depends on sampling frequency and the input DC level), this special architecture easily handles DC inputs:

- Very high oversampling ratio (OSR): For our ΣΔ ADC, OSR > 10000x. Typical ΣΔ ADC's have OSRs on the order of ~256x. (A new project at Berkeley has has a ΣΔ ADC with OSR = 40000x)
- To maximize DC accuracy, the integrators are reset after every conversion. Normal ΣΔ ADC's don't do this.
- A first-order sinc filter is used as the decimating filter. This allows offset trimming and autozeroing for DC applications.

ΣΔ ADC's are very accurate, but slow compared to a SAR architecture. ΣΔ ADC's can achieve >20 bits of accuracy, where SAR ADC's are only practical up to about 12-bits, since they are limited by their DAC linearity. The SAR is a faster architecture, but speed is unnecessary for slow changing signals like temperature.
This particular ΣΔ ADC inherently averages the input, giving better noise rejection.

Noise Performance Torture Test 1



This is all wonderful in theory, but how does it work in the real world? We did some tests. A Pentium processor doing continuous real-time, high-speed 3D-rendering generates a lot of thermal changes, and a PC motherboard is a pretty noisy environment. How much of the Pentium's signal (D3+) and the motherboard's noise will show up in the D1 and D2 channels?

Experiment Conditions:

2 RDTS channels go to 2 diode-tied MMBT3904 transistors

3rd Channel tied to diode on a Pentium® II in a PC

PC running graphics application under Windows

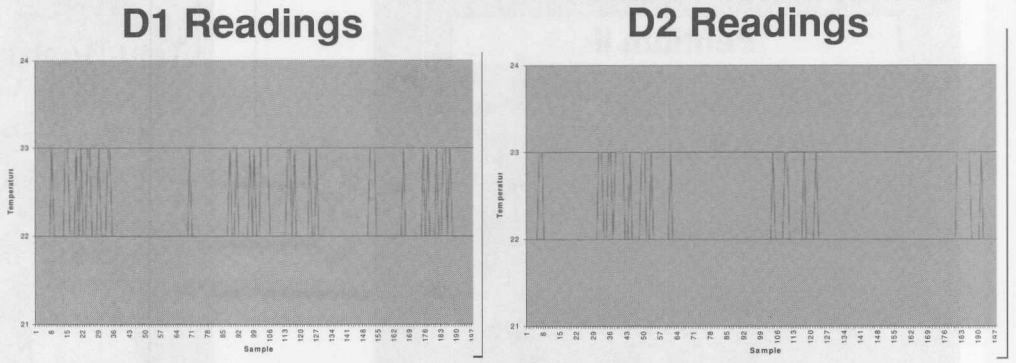
Connection using 15" braided ribbon cable

No ground shielding

A separate PC logged readings to ensure data is recorded while the noisy application is running

An HP 3631A bench power supply provided external power to the LM83

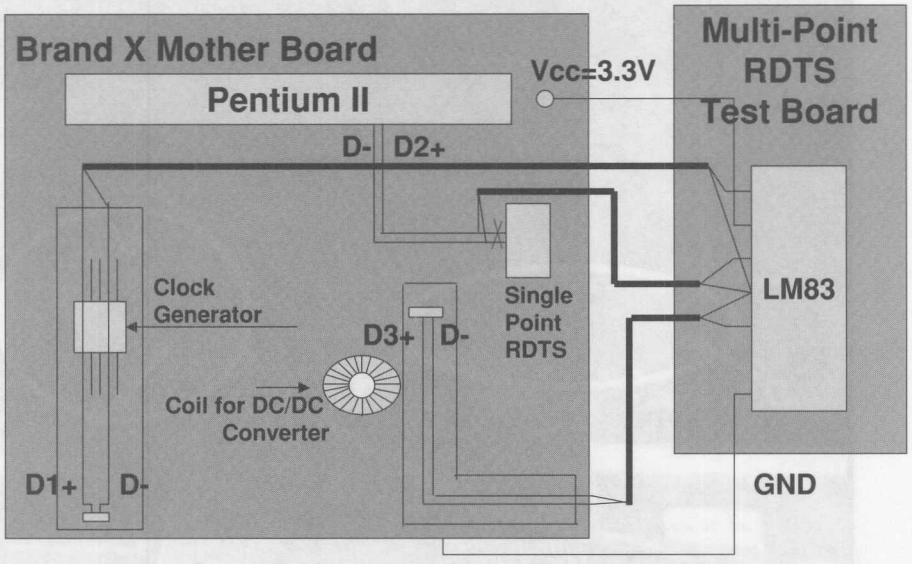
Noise Performance Torture Test 1: Results



All readings are 22°C or 23°C. There is no noise coupled!

The two remote diode channels show only ADC quantization nose (flipping back and forth between two adjacent codes). But this wasn't really ***that*** torturous a test…we can do better!

Noise Performance Torture Test 2



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Analog Applications 57

This time we used a 400MHz Pentium II processor motherboard, drew the power supply for the LM83 from the PC's 3.3V supply, and ran our other two remote diodes all over the motherboard. Conditions:

Experiment Conditions:

D1 is placed on a flex circuit that is taped over the Pentium' clock generator chip (the SG577D from International Micro Circuits)

D3 is placed on a flex circuit that is wrapped and taped around the inductor of a switching DC/DC power converter!

3rd Channel tied to diode on a Pentium® II in a PC

400MHz Pentium II was running graphics application under Windows

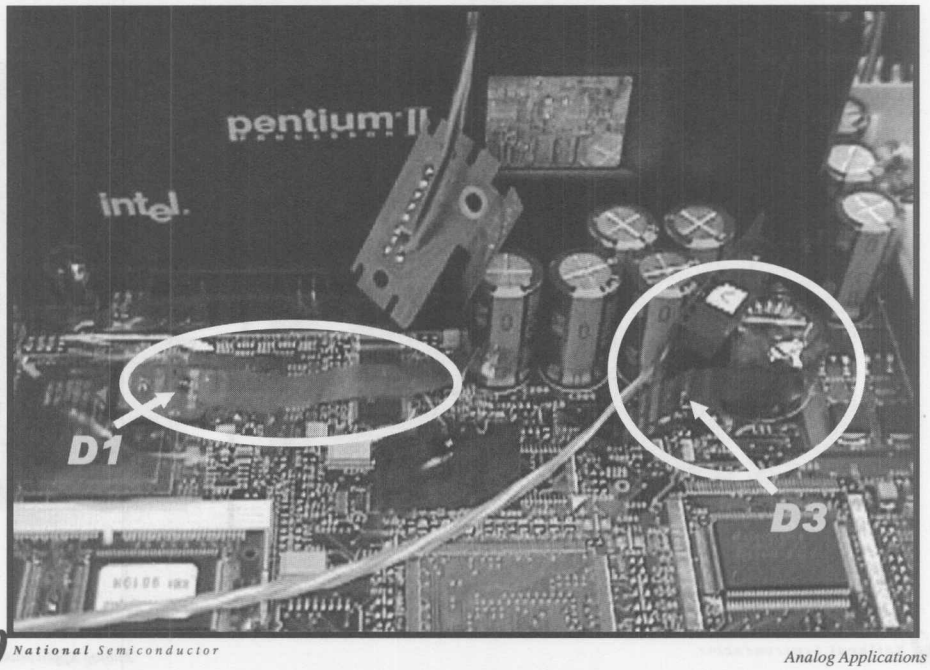
Connection using 15" braided ribbon cable to the flex circuit as well at the Pentium II thermal diode traces (the single RDTS device traces were cut very close to the RDTS IC)

No ground shielding

A separate PC logged readings to ensure data is recorded while the noisy application is running

The power for the LM83 was tapped off the Pentium II mother board.

Noise Performance Torture Test 2

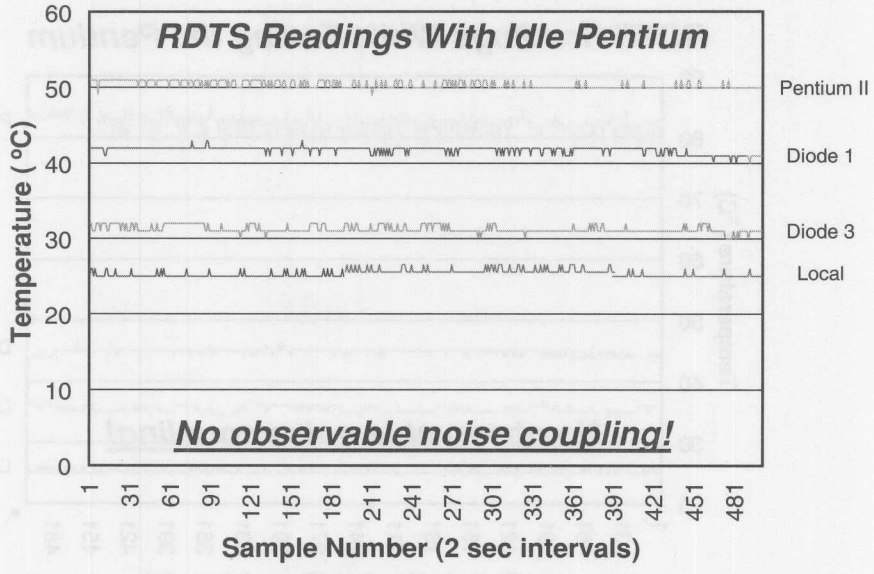


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Analog Applications 58

We're not kidding!

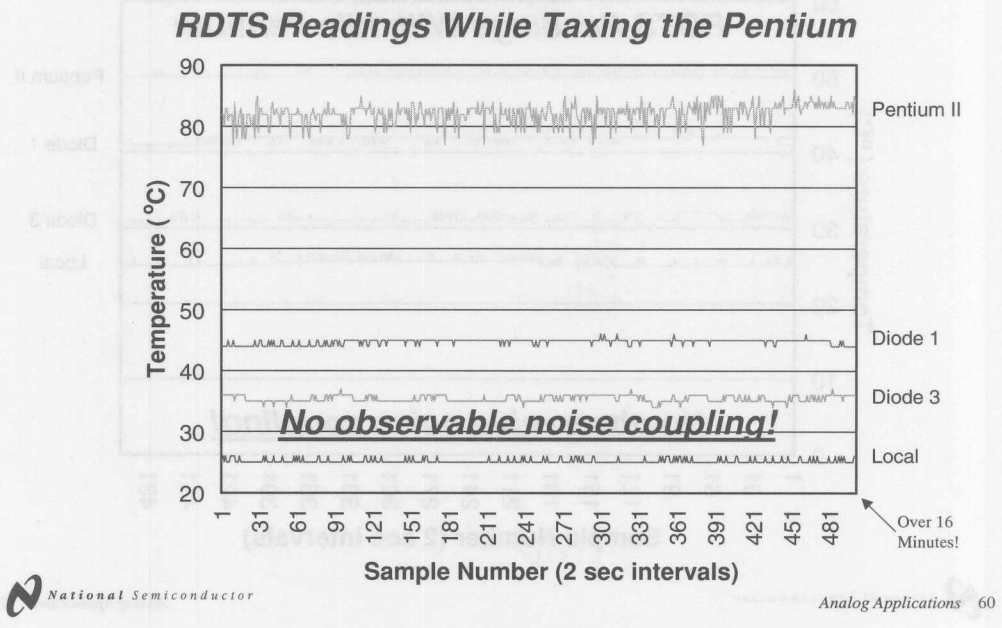
Noise Performance Torture Test 2



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With the Pentium idling, there's no observable noise coupling. Here we show approximately 500 samples taken at 2 second intervals. The actual temperature reading is on the y axis.

Noise Performance Torture Test 2

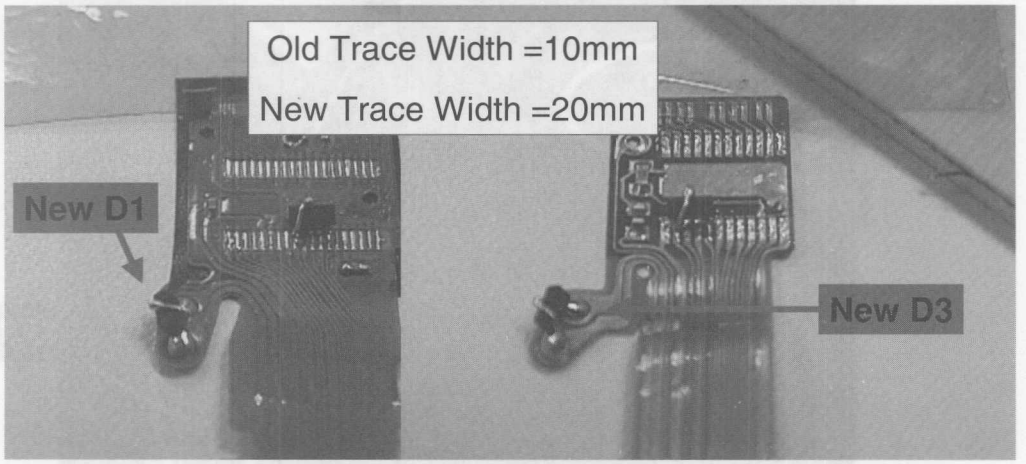


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Analog Applications 60

When running the CPU-intensive 3D rendering software, all readings are still essentially noiseless – on Diodes 1 and 3 there's no noise greater than the quantization noise of the ADC riding on top of the low frequency temperature change that takes place over the 16 minute-long test period. The Pentium II reading may appear to be noisy, but it's hard to tell whether the noise is caused by thermal variation of the die or substrate noise coupling into the Pentium II's thermal diode. Notice how the other channels, Local, Diode 1 and Diode 3, are not affected by the third noisy channel.

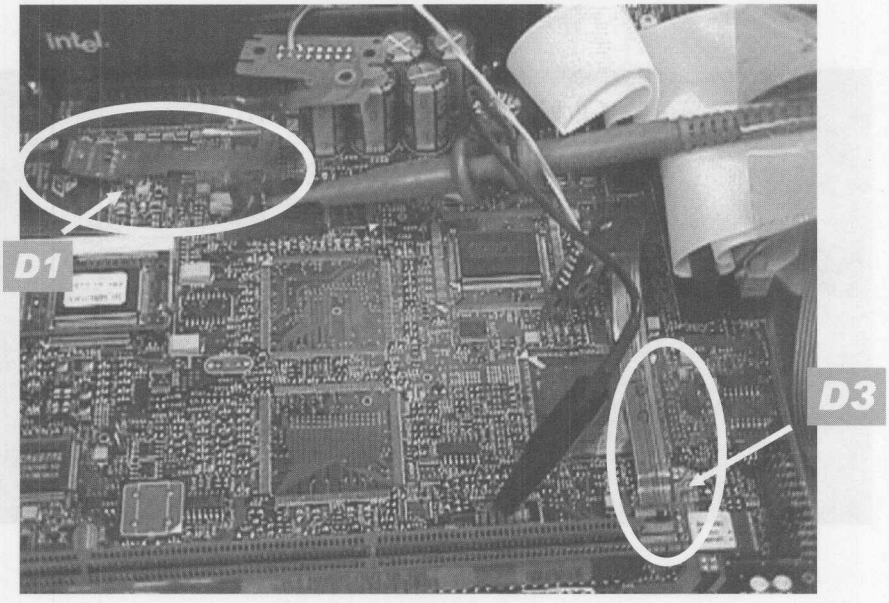
Noise Performance Torture Test 3



Does Trace Width Matter?

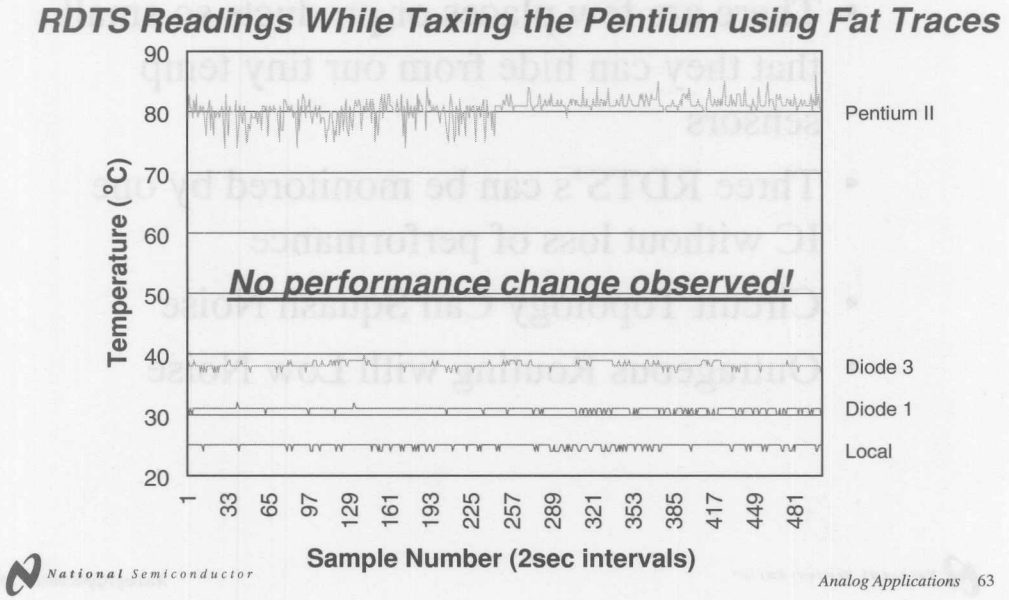
The final question we wanted to answer was the question of trace length. Would wider, lower inductance, lower impedance traces between the remote diode and the LM83 affect noise in any way? We doubled the width of the traces…

Noise Performance Torture Test 3



Here's the layout for Test 3. Notice that we moved Diode 3 to an area of the board that was not noisy.

Noise Performance Torture Test 3



No change! The Pentium II signal level change mid-stream is caused by the random nature of the 3-D graphics software that was being used for the experiments.

Summary

- There are few places or products so small that they can hide from our tiny temp sensors
- Three RDTS's can be monitored by one IC without loss of performance
- Circuit Topology Can Squash Noise
- Outrageous Routing with Low Noise

Collateral:

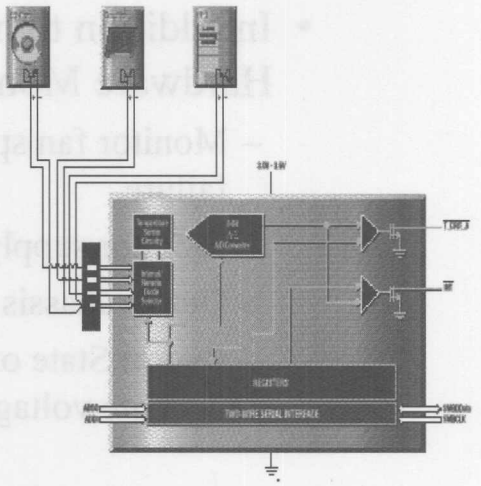
- http://www.national.com/appinfo/tempsensors
 - info on multiple RDTS
 - RDTS Data sheets:
 LM82, LM83, LM84, LM87,
 SuperI/O(PC87365, PC87366)

Temp Sensor Appendix

World's First Triple-Diode Input and Local Digital Temperature Sensor

LM83:

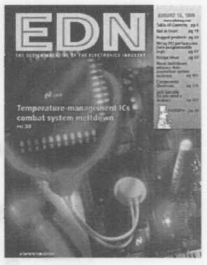
- Three Remote Diode Temperature Sensing (RDTS) Inputs
- Common D- pin
- 7-Bit + sign temperature data format with 1°C resolution
- SMBus 1.1 compliant and I^2C compatible Interface - Supports SMBus Timeout
- 2 Interrupt pins: INT and T_CRIT_A
 - INT is set when any temperature reading goes above its corresponding set-point.
 - T_CRIT_A is set when any temperature reading goes above the common programmable set-point. Any reading may be masked off in the configuration register.



System Hardware Monitoring

- In addition to measuring temperature Hardware Monitors:
 - Monitor fan speed to detect impending failure.
 - Monitor supply voltages.
 - Detect chassis intrusion.
 - Report State of processor VID pins that set the core voltage.

System Hardware Monitors



LM80 : 2.8 to 5.7 V supply

LM81 : 9-12b, SMBus

LM87 : LM81 + 2x RDTS

Additional Temp & Voltage Sensors

Fan Speed Control DAC

New

Remote CPU Sensing, Voltage & Fan Controls

System Hardware Monitors

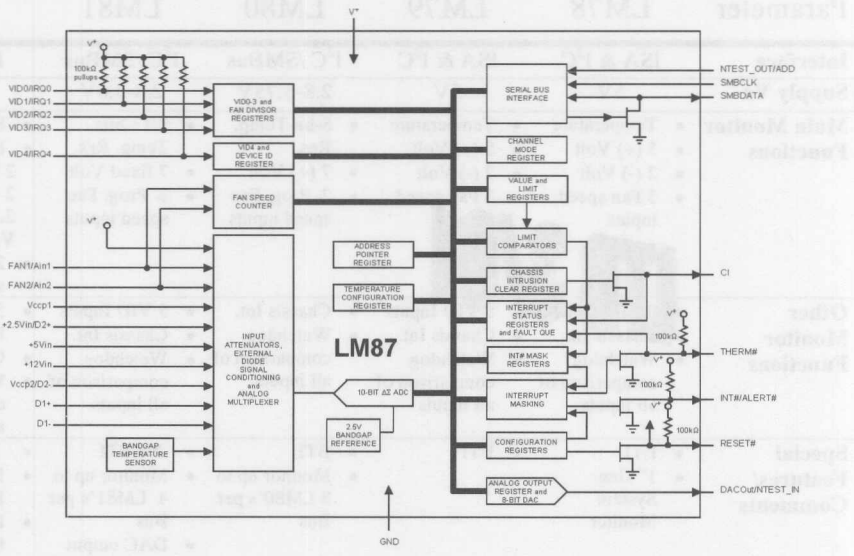
- LM80
 - Monitors 7 voltages, 2 fan speeds and multiple analog and digital temp sensors
 - Watchdog limits, interrupts, 2-wire serial interface
 - Analog inputs need external resistors for monitoring Voltage
- LM81
 - Same as LM80 except:
 - 5 VID monitoring inputs, D/A for fan control
 - No BTI(INT & I2C used instead), 6 analog inputs
 - On board resistors for monitoring preset Voltages
- LM87
 - Same as LM81 except:
 - Integrated 2 LM84 Remote Diode Temperature Sensors (RDTS)
 - VID inputs selectable as IRQs
 - Fan inputs selectable as analog inputs

Hardware Monitor
Feature Highlights

Parameter	LM78	LM79	LM80	LM81	LM87
Interface	ISA & I^2C	ISA & I^2C	I^2C /SMBus	I^2C /SMBus	I^2C /SMBus
Supply Vs	5V	5V	2.8-5.75V	2.8-3.8V	2.8-3.8V
Main Monitor Functions	• Temperature • 5 (+) Volt • 2 (-) Volt • 3 Fan speed inputs	• Temperature • 5 (+) Volt • 2 (-) Volt • 3 Fan speed	• 8-bit Temp. Res. • 7 (+) Volt • 2 Prog. Fan speed inputs	• 9/12-bits Temp. Res. • 7 fixed Volt • 2 Prog. Fan speed inputs	• 8-bit Temp. Re • Inputs (up to): 2 D+ and D- 2 Vccp 2.5, 3.3, 5, 12 Vin • 2 Prog. Fan speed/Ain inpu
Other Monitor Functions	• 0 VID Inputs • Chassis Int. • Watchdog comparison of all inputs	• 5 VID Inputs • Chassis Int. • Watchdog comparison of all inputs	• Chassis Int. • Watchdog comparison of all inputs	• 5 VID Inputs • Chassis Int. • Watchdog comparison of all inputs	• 5 VID/IRQ Inputs • Chassis Int. • Watchdog comparison of all inputs
Special Features/ Comments	• BTI • 1st Gen. System Monitor	• BTI	• BTI • Monitor up to 8 LM80's per Bus	• No BTI • Monitor up to 4 LM81's per Bus • DAC output for fan control	• No BTI • Monitor up to 3 LM87's per Bu • DAC output fo fan control

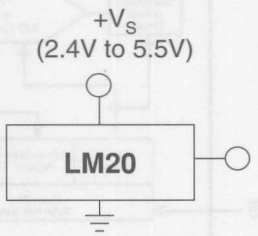
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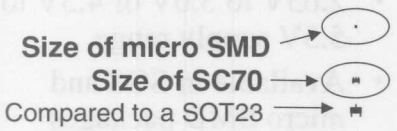
LM87 Hardware Monitor



LM20 Analog Output Temp Sensor

- ±1.5 °C or ±4 °C accuracy at 25 °C
- ±2.5 °C or ±5 °C accuracy at -55 and +130 °C
- Temperature can be extended to -55 °C with 2.8V Supply
- I_Q < 10 µA max
- Low Self-Heating (0.02 °C in still air)
- ±0.4 % Non-Linearity over -20 to +85 °C
- Parabolic curvature defined and specified for best optimization of accuracy

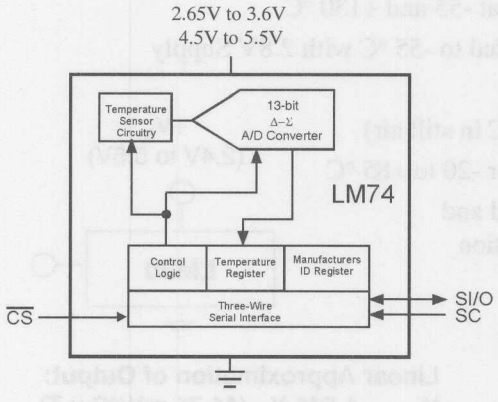




Linear Approximation of Output:
V_{OUT} = 1.841 V - (11.71 mV/°C x T)
for -10 °C to +65 °C

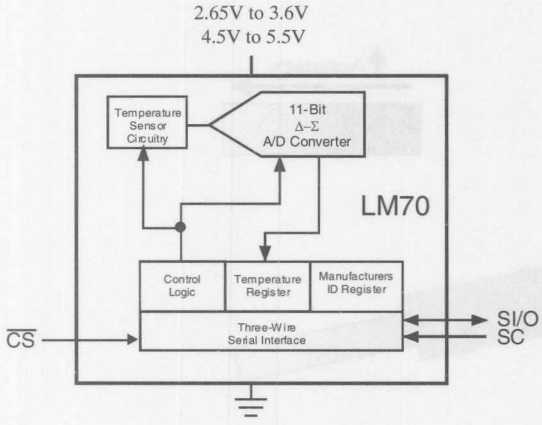
The LM20 has recently been released in the SC-70 and micro SMD packages. The SC-70 package is about 3/4 the size of the SOT-23. The 4 lead micro SMD package is slightly bigger than the die itself, which is the size of a grain of sand. We are specifying this part to a parabolic second order transfer function, rather than a linear one shown, so that overall system accuracy can be optimized. This enables us to release the most accurate small temperature sensor to date.

LM74 Digital Output Temp Sensor



- Simple SPI/MICROWIRE Serial Interface
- Low Cost Bare Bones Temperature Sensor
- 12-Bit + Sign Resolution
- Better than 1.25°C Accuracy
- 2.65V to 3.6V or 4.5V to 5.5V supply range
- Available in SO8 and micro SMD packages

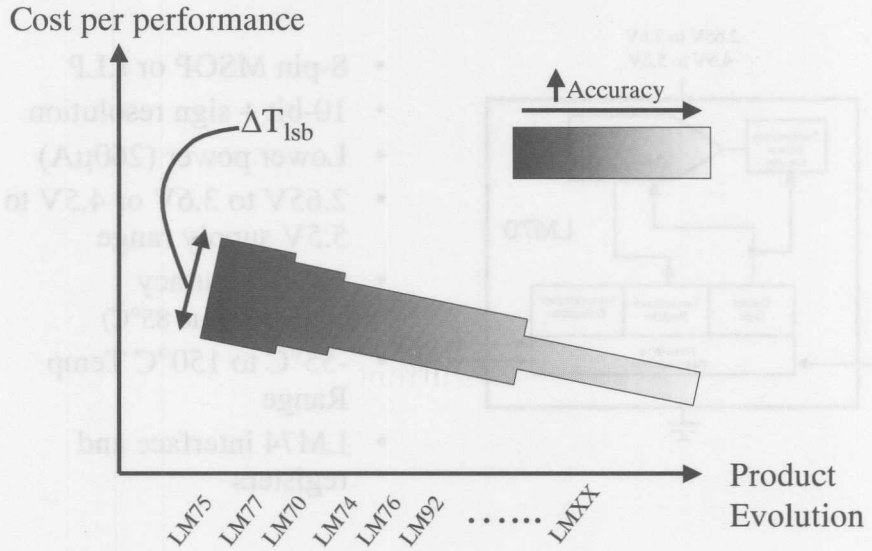
LM70 Digital Output Temp Sensor



- 8-pin MSOP or LLP
- 10-bit + sign resolution
- Lower power (260µA)
- 2.65V to 3.6V or 4.5V to 5.5V supply range
- ±2°C Accuracy (-40°C to 85°C)
- -55°C to 150°C Temp Range
- LM74 interface and registers

Our simplest/smallest digital temperature sensor to date. The LM70 is basically an LM74 with reduced resolution and resultant lower power consumption. Die size reduction from the LM74 allowed it to fit in the 8-lead MSOP package as well as the 8-lead LLP package.

High Accuracy Digital Temperature Sensor Product Evolution



High Accuracy Digital Temperature Sensors with 2-wire Interface

LM76CNM:

- 12-bit plus sign output (Can Resolve Temperatures >127°C) 0.0625°C/LSB
- Accuracy: ±1°C from 70°C to 100°C
 ±2.5°C from -25°C to 125°C
- Operating Supply Current = 250μA
- Shutdown Supply Current: 5μA
- Supply Voltage = 3.0V to 3.6V

Sensors with 2-wire Interface

LM76CHM, same as LM76CNM with the exception of:

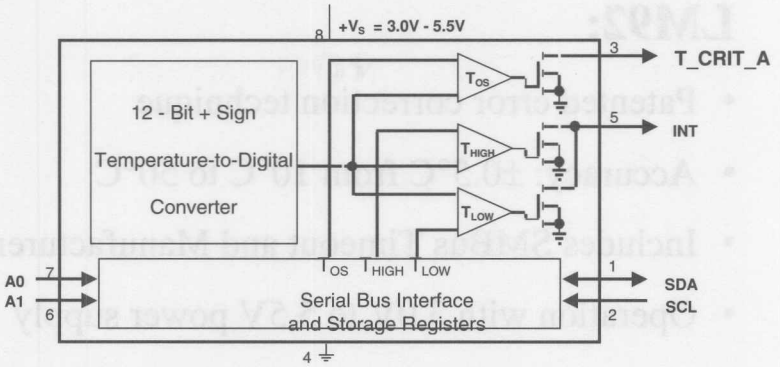
- Accuracy: ±0.5°C at 25°C
- Accuracy: ±1.0°C from -10°C to 40°C
- Accuracy: ±1.5°C typ from -20°C to 85°C
- Supply Voltage = 4.5V to 5.5V

Highest Accuracy 2-Wire Interface Temperature Sensor

LM92:

- Patented error correction technique
- Accuracy: ±0.5°C from 10°C to 50°C
- Includes SMBus Timeout and Manufacturers ID
- Operation with 3.0V to 5.5V power supply

LM76CNM, LM76CHM and LM92 Block Diagram

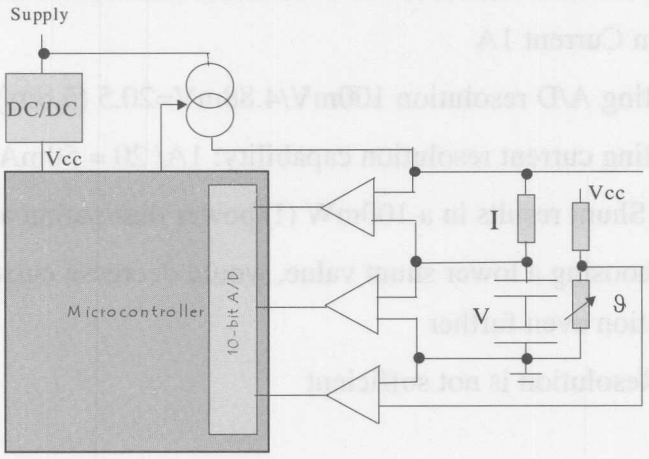


8-BIT MICRO CONTROLLER WITH INTEGRATED PROGRAMMABLE GAIN AMPLIFIER IN 10-BIT A/D SIGNAL PATH

Agenda

- A/D Conversion with Microcontrollers the Traditional Way
 - -Effective resolution when measuring small analog signals without amplification
 - -Effective resolution when measuring small analog signals with external amplification
- Integration and Sub-Miniature Packages as Ways to Reduce External Component Count and PCB Real-Estate Area
 - -Chip Scale Package Technology
 - -Integrating Operational Amplifiers
 - -Programmable OpAmp in A/D Path
 - -A/D Filter Path
- New Microcontroller System Development Challenges Triggered by Higher Analog Integration

The Traditional Way



Above Figure shows the block diagram of a typical analog signal processing system built around a microcontroller. The microcontroller features an integrated A/D converter and is used to process a variety of signals. In our example various analog sensor outputs

Battery voltage change

Battery charge current, and

Battery temperature

are measured. The microcontroller's A/D voltage reference is typically tied to the chip's Vcc supply (5V in example)

The A/D converter thus has a full scale dynamic range of 0V…5V.

Assuming a 10-bit resolution, this translates into a **voltage step of 4.88mV per bit.**

Now let's look at the output characteristics of each of our analog sensors in more detail.

Current Measurement

- Example: Current measured via a 0.1 Ohms Shunt Resistor. Maximum Current 1A
 - Resulting A/D resolution 100mV/4.88mV=20.5 (5 bits)
 - Resulting current resolution capability: 1A/ 20 = 50mA
- 0.1 Ohm Shunt results in a 100mW (!) power dissipation at 1A
 - but choosing a lower shunt value, would decrease current resolution even further
- Current Resolution is not sufficient

One parameter to be measured in our example system, is the charge current for the battery and the current flowing into the system powered by the battery. This is usually done using the shunt resistor and the trade-off that has to be made is minimizing the voltage drop over that resistor (to minimize heat dissipation and measurement error), while at the same time getting a reasonable resolution of the measured current.

Let's assume our charge/supply current that we want to measure is a maximum 1A, however in certain modes current can drop below the 1mA level and we want to be able to measure this current as well. A 0.1Ω resistor in the supply line would result in a 0.1V voltage drop in the supply at 1A.

Without amplification, our A/D would only see a maximum 100mV input voltage, giving us an A/D resolution of 100mV/4.88mV=20.5 (5 bits), which translates into a current resolution capability of 1A/20.5= 48.8mA, not very exciting.

Amplified Current Measurement

- Example: Current measured via a 0.1 Ohms Shunt Resistor. Maximum Current 1A
 - Using a Operation Amplifier with a Gain of 50 will amplify the 100mV voltage drop to 5V
 - the resulting current resolution capability increases to 1A/1024 = 976.56 uA
- Current resolution has been improved by a factor of 50
- Power dissipation can be cut in half by doubling amplification to 100 and reducing shunt value to 0.05 Ohms

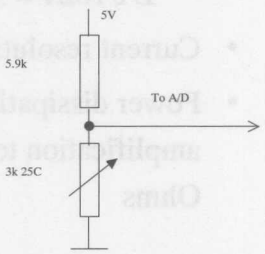
Amplifying the 0.1V voltage drop by a factor of 50, gives us a full 5V input voltage delta, resulting in a current resolution capability of

1A/1024 =976.56uA.

Another advantage amplification offers is to further reduce the value of the shunt resistor. Increasing amplification to 100 while reducing the shunt value to 0.05 Ohms will decrease power dissipation to 50mW. At the same time full resolution is maintained.

Temperature Measurement

- Example: NTC resistor, β of 2988, 3kΩ at 25°C
 - resistive value changes from 0.5kΩ to about 7.7kΩ over -10°C to +50°C temperature range.
 - -10°C: 5V x 0.5kΩ/(5.9kΩ+0.5k Ω)=390.63mV
 - +50°C: 5V x 7.7k Ω /(5.9k Ω +7.7k Ω)= 2.831V
- Resulting A/D Resolution
 (2.831V-390.63mV)/4.88mV= 500
- Temperature resolution
 60°C/500= 0.12°C



To measure the battery temperature, a negative temperature coefficient (NTC) resistor is used.

A typical NTC resistor with a β of 2988 and a value of 3kΩ at 25°C, changes its resistive value from approximately 0.5kΩ to about 7.7kΩ over a temperature range of -10°C to +50°C.

If such a temperature sensor is used without additional amplification, a typical result looks as follows (assuming the NTC's voltage change with temperature is linear, which of course it is not, but this is of no relevance for the point we are trying to illustrate.):

The minimum voltage measured by the A/D at -10°C is:

5V x 0.5kΩ/(5.9kΩ+0.5kΩ)=390.63mV

The maximum voltage measured by the A/D at +50°C is:

5V x 7.7kΩ/(5.9kΩ+7.7kΩ)= 2.831V

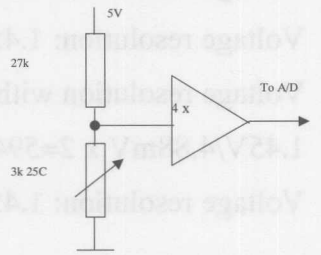
So the voltage delta over temperature is 2.440V, utilizing only half of the A/D's full dynamic range. Assuming, for a moment, the NTC's voltage change is linear, this translates into an A/D resolution of 2.440V/4.88mV= 500 (< 9 bits), which in terms of the temperature range to be measured would give us a temperature resolution of 60°C/500= 0.12°C.

Amplified Temperature Measurement

- Example: Same NTC resistor with 4x amplification
 - -10°C: 5V x 0.5k Ω /(27k Ω +0.5k Ω) x 4= 363.6mV
 - +50°C: 5V x 7.7k Ω /(27k Ω +7.7k Ω) x 4= 4.438V
- Resulting A/D Resolution

 (4.438V-363.6mV)/4.88mV= 835
- Temperature resolution

 60°C/835 = 0.072°C



Amplifying the voltage drop over the NTC resistor by a factor of 4 yields the following results:

Note: The resistor in series with the NTC has been increased from 5.9k to 27k, which in combination with the 4x amplification actually improves our dynamic input voltage range at the low end (at -10C) (from 390mV to 363mV) as well as at the high end (+50C)(from 2.83V to 4.43V)

The minimum voltage measured by the A/D at -10°C is:

5V x 0.5kΩ/(27kΩ+0.5kΩ) x 4= 363.6mV

The maximum voltage measured by the A/D at +50°C is:

5V x 7.7kΩ/(27kΩ+7.7kΩ) x 4= 4.438V

The voltage delta over temperature is 4.074V. Assuming again, for a moment, the NTC's voltage change is linear, this would translate into an

A/D resolution value of 4.074V/4.88mV= 835,

which in terms of the temperature range to be measured gives us a temperature resolution of 60°C/835= 0.072°C.

So, by adding the amplifier into our system design, we have substantially improved our capability to do a finer grained temperature measurement.

Battery Voltage Measurement

- Example: Single Cell NiMH or NiCd
 - maximum cell voltage:1.45V
 - minimum cell voltage: 0.9V
- End of charge termination via -ΔV
 - Voltage resolution without amplification: 1.45V/4.88mV= 297

 Voltage resolution: 1.45V/297 = 4.88mV

 Voltage resolution with 2x amplification:

 1.45V/4.88mV x 2=594

 Voltage resolution: 1.45V/594 = 2.44mV

Another parameter to be measured in our example system is the voltage change of the battery over time to determine charge termination.

A rechargeable NiCd or NiMH battery has a typical cell voltage of 1.2V.

The maximum voltage when fully charged is 1.45V,

the minimum voltage when discharged is 0.9V.

One of the methods to do charge termination is -ΔV, i.e. at the end of charge the cell voltage drops slightly. Assuming a one cell configuration and no amplification, we utilize a resolution of the A/D of

1.45V/4.88mV= 297 (< 9 bits).

Amplifying the voltage by a factor of two we get

2.9V/4.88mV= 594 (<10bit).

This, in terms of the actual voltage we are trying to measure, gives us now, of course, twice the granularity: 1.45V/594 = 2.44mV

Conclusions

- Many analog signals require external amplification to utilize the full resolution of an A/D converter integrated on a microcontroller
- For each analog signal that requires amplifcation one external OpAmp is needed
 - Significant number of external components (OpAmps, resistors, buffer caps)

Result: increased system cost and PCB real-estate area

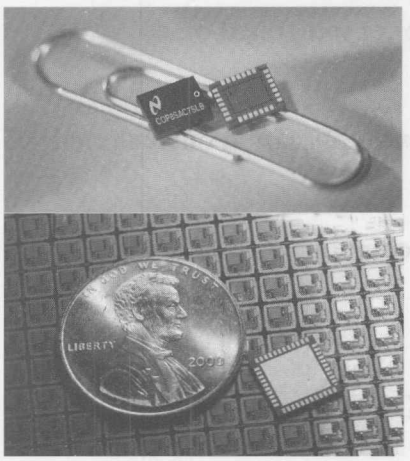
In summary, it can be stated that, with the traditional way of adapting the analog signals to the full dynamic range of the A/D, external OpAmps are required in most applications

Depending on the application, the number of external OpAmps increases with the number of analog signals that need to be processed, resulting in a significant number of external components (OpAmps, resistors to set the amplification factors, and Vcc buffer caps) that increase system cost and required PCB real-estate area.

Where PCB real estate area is a critical factor, it can be addressed in two ways: integration and sub-miniature packaging technology.

Before we take a closer look at the possibilities that integration provides, we take a short look at new sub-miniature package technology available for microcontrollers: chip scale packaging.

Chip Scale Packaging



- Significant Board space savings.
 - 28 CSP 68% smaller than TSSOP 28
 - 44 CSP 66% smaller than PQFP 44
 - Just 7mm x 7mm x 0.8mm
- More I/O per mm^2.
- Lower Pin Inductance and Capacitance
- Superior Thermal Performance

National Semiconductor started offering its microcontrollers in a new package, called Chip Scale Package (CSP) about a year ago.

The package provides significant space saving when compared to traditional SO packages, while at the same time giving a larger number of I/Os per available mm^2 of board area.

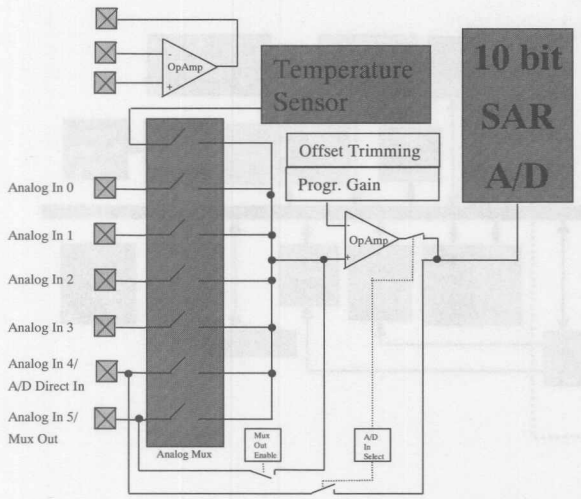
Compared with a 44 pin plastic quad flat package (PQFP), a 44 pin CSP package is 66% smaller (7mm x 7mm x 0.8mm).

The 28pin CSP package is 68% smaller than a 28 pin TSSOP package and has about the same physical size as an 8pin SO, but gives the user 24 I/Os versus 4 I/Os of the SO8 package.

Especially when it comes to analog performance the package offers distinct advantages, as pin inductance and capacitance are minimized, due to the very short leads.

At the same time thermal performance of the package is superior, due to a large heat conductive contact surface with the PCB.

COP8AME A/D-OpAmp Block Diagram



- Saves up to 7 external OpAmps (one per A/D input and one through second integrated OpAmp)
- A/D filter path allows to add external
 - filters
 - additional A/D inputs through mux
- Scale analog input signals to utilize full A/D resolution

National Semiconductor

Analog Applications 11

Figure above illustrates an implementation on one of National Semiconductor's COP8 microcontrollers, where a programmable gain amplifier has been integrated between the output of the on-chip analog input multiplexer and the 10-bit successive approximation A/D.

The OpAmp is software programmable with different gain factors of 1, 2, 5, 10, 20, 50 and 100. It can also be completely bypassed. The OpAmp is designed with high impedance, rail-to-rail inputs and rail-to-rail output.

The input offset of the OpAmp can be as much as ±7mV. For this reason, circuitry for trimming out the offset, by the user, has been provided. By doing two measurements, one with an amplification factor of 1 and one with an amplification factor of 20, the user can trim the offset for both the N-channel and the P-channel input stage pairs in 0.5mV steps. At the end of this calibration process the input offset voltage is 500uV or less.

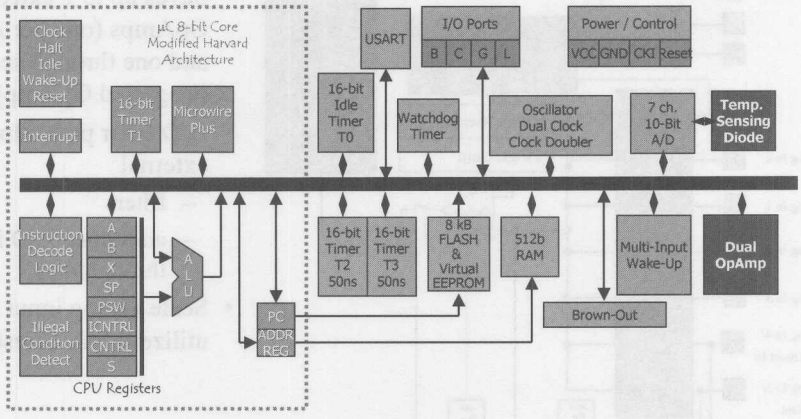
The analog input multiplexer supports 7 inputs, of which one is dedicated to the on-chip temperature sensor, providing a total of 6 external analog inputs.

Rather than requiring up to 6 external OpAmps and passive components for designs utilizing all of those analog inputs, the implementation discussed here can handle all that functionality with the one integrated, programmable gain OpAmp.

A second "standard" operational amplifier is integrated with both inputs and its output accessible externally via the microcontroller's pins. This OpAmp can be utilized to implement an active filter function (e.g. noise filtering), an independent amplification or buffer stage, or other OpAmp function.

The analog input multiplexer's output provides a path back to one of the input pins and a second input pin provides a direct connection to the 10-bit A/D input, so that another, external circuit can be inserted into the A/D conversion path.

COP8AME Block Diagram



The block Diagram above shows the COP8AME microcontroller, a device with a

- 10-bit A/D SAR, dual OpAmps and integrated temp sensor as discussed on the previous foil
- 8k bytes of FLASH memory
- 512 bytes of RAM
- Three 16-bit multifunction timers - that support
 - *processor independent PWM,*
 - *capture and*
 - *event counter modes*
 - *at a resolution down to 50ns,*
- Full duplex USART with integrated baud rate generator,
- Microwire™ 3-wire synchronous interface,
- Brown-out reset,
- Clock doubler, and dual clock function.

 The dual clock feature allows the user to connect an optional 32kHz low speed oscillator to enable real-time clock functions or control tasks requiring low computing performance at extremely low power consumption levels. For higher performance tasks the user can switch under software control to the high speed main oscillator (500ns instruction cycle at 10MHz).

 The COP8FLASH devices consume typically less than 3mA at 3.0V Vcc and a main clock of 3.3MHz. Switching to the low speed 32kHZ oscillator reduces current consumption to a typical 24uA. In IDLE mode, where only the 16-bit Idle timer is running (real-time clock), the part typically consumes only 2.7uA.

The virtual EEPROM features allows the user to dynamically allocate any desired amount of FLASH program memory for data storage, thus eliminating the need for external EEPROM

Analog System Development Challenges

- Integrated OpAmp:
 - Signals in the mV or even uV range have to be routed to the microcontroller's A/D pins
 - Short traces are critical to minimize noise, inductance and capacitance.
- Integrated Temperature Sensor:
 - Microcontroller has to be physically placed where temperature is to be measured
- Subminature packaging in area or height restricted applications:
 - No sockets, emulation towers, different form factor packages can be used

As beneficial as the integration of a programmable OpAmp and temperature sensors onto a microcontroller are in terms of external component count reduction, it creates a series of new challenges when it comes to application development, which usually involves the writing and debugging of code.

The debugging of code requires a real-time, in-system emulator for the microcontroller, which allows the software developer to rapidly make changes to the code during the development phase and to check it out in the final end application. At the same time, the emulator provides powerful PC based debugging tools that support capabilities like examining on-chip registers, setting breakpoints at defined points in the program flow and looking at a history of executed code (trace).

Existing emulators today use one of two approaches, which for the purpose of this discussion we would like to call the "probecard" approach and the "debug board" approach.

Existing Approaches to Emulation

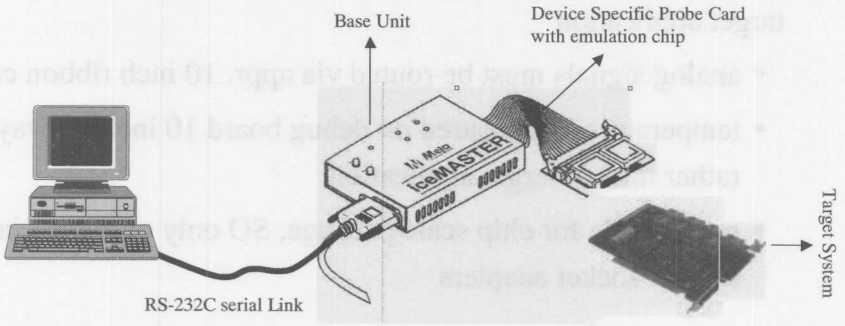
- Probe card method
 - base unit & probe card with bond out chip
 - analog signals are routed via socket connector to probecard PCB and via traces of PCB to socketed bond out chip
 - Temperature is measured on the probecard and not in the target application
 - Not feasible for chip scale package, SO only possible via cumbersome package adapters.

The probecard approach uses a, so called, base unit that is connected to a PC via the serial port. The base unit contains the majority of the emulator electronics, with the exception of the emulation chip itself. The emulation chip is a special bond-out version of the actual microcontroller and is mounted on a separate small PCB, called a probecard. This probecard connects via a ribbon cable to the base unit and has different socket adapters at the bottom, that allow the probecard to be plugged into the actual target application board.

What this means for analog signals that connect to the microcontroller is, that they have to travel from the target board, via a chip-socket, via another pin adapter socket on the probecard, via the PCB traces of the probecard to the actual microcontroller pins.

One can easily envision that this approach introduces additional noise, capacitance and inductance that make it impossible to obtain the same analog signal behavior during emulation as in the final production version where the microcontroller sits directly on the target board.

Probe Card Emulation Method

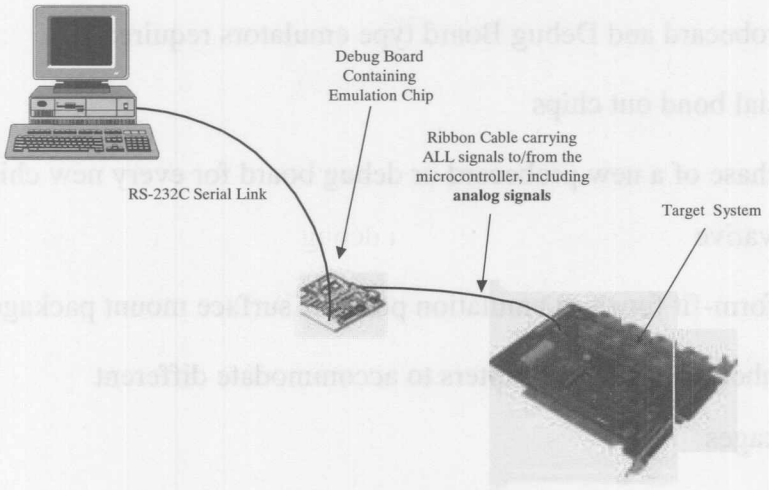


Existing Approaches to Emulation

- Debug board method
 - single board, ribbon cable connects to socketed connector on target application
 - analog signals must be routed via appr. 10 inch ribbon cable
 - temperature is measured on debug board 10 inches away rather than in target application
 - not feasible for chip scale package, SO only possible via special socket adapters

The "debug board" approach combines all of the emulator electronics and the actual emulation chip onto a single, larger sized PCB. The connection to the target system is accomplished by ribbon cables, which provide, on one end, a connector that can plug into an actual chip package socket. This means that all pin signals for the microcontroller to be emulated are now routed via this ribbon cable that connects the target system with the debug board, including any analog signals to be measured by the microcontroller. This is bad enough if already amplified analog signals are routed via such a cable, as additional noise, capacitance and inductance are introduced that falsify the original analog signal, but it becomes even worse, if the amplification is now done within the microcontroller and analog signals in the mV or even uV range are routed via such a cable- the results become unusable. Also, as analog functions, such as a temperature sensor, get integrated into a microcontroller, you want to measure the temperature at a specific point in the end application and not the ambient temperature of the debug board!

Debug Board Method



More Drawbacks

- Both Probecard and Debug Board type emulators require:
 - special bond out chips
 - purchase of a new probecard or debug board for every new chip derivative
 - No form-fit function emulation possible surface mount packages
 - Cumbersome socket adapters to accommodate different packages

Another draw-back of both probecard and debug board approaches is, that they require a specialized bond-out chip, for each new microcontroller derivative. This makes the debug board or probecard specific to a given device, a new probecard or debug board needs to be purchased if new family members with new integrated features are introduced.

Both approaches were developed in the days of dual-inline packages. Emulation of surface mount package is only possible by using cumbersome (and sometimes very expensive) special socket adapters. Even then those approaches do not allow for true form-fit factor emulation as bulky clip or tower constructions sit on top of the socket adapter.

Form-fit factor emulation of leading edge chip scale packages is impossible.

National's 100% precise analog emulation

- FLASH program memory allows for in-application (re-) programming
- Each microcontroller contains it's own emulation support circuitry
 - A sample of the chip can be soldered directly into the target system, regardless of package
 - The uC "sees" exactly the same analog environment as in the final product
- Emulation interface requires only 4 digital I/O pins, which are fully recreated by the COP8FLASH emulators

National Semiconductor

Analog Applications 19

The solution to the previously illustrated problems comes with the advent of FLASH program memory and a new approach in microcontroller emulation pioneered by National Semiconductor: 100% precise analog emulation.

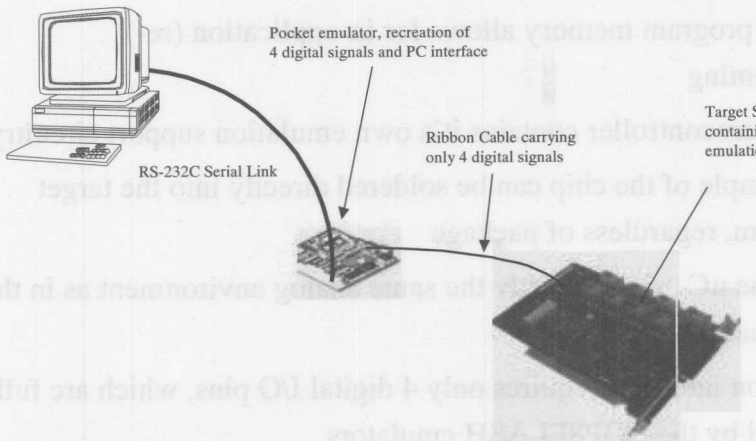
Through the electrical erase/write capability of FLASH program memory, in combination with emulation support circuitry and code embedded in the microcontroller, each chip can be its own emulator.

This means that a sample of the microcontroller chip, regardless of package, can be directly soldered into the target application. This, of course, means that now the microcontroller chip "sees" the exact same analog environment as the final application. Temperatures, for example, are measured where they are supposed to be measured and voltages in the uV to mV range that need to be amplified only need to travel the shortest possible distance.

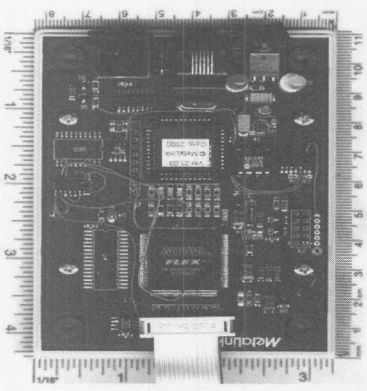
The only connection now required to enable PC based software debugging are four fully digital I/O pins of the controller, whose digital functions are "recreated" on a small piece of hardware that sits between the PC and the target system. This connection from the target board to the base is accomplished via a small 2 x 7 header on the target board that, at the same time, can be used to program and re-program the controller in-system without the need for any additional programming support circuitry.

As mentioned earlier, the chip is its own emulator, so that when a new family member is introduced, no new emulator or probecard needs to be purchased- all that is required is a sample of the new chip and eventually a software update for the debugger software that runs on a PC.

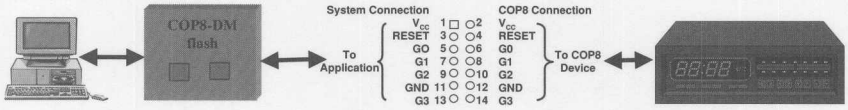
National's 100% precise analog emulation



In-System Emulation Tools



- **Customer Benefits:**
 - **Precise Analog Emulation**
 - **Easy in-field debugging**
 - **Eliminates expensive bond-out chip**
 - **Low-Cost Emulation**
 - **Target Connection via** (2x7) **Header**



CONCLUSION

The integration of a programmable gain amplifier into the on-chip A/D signal path of a microcontroller, can provide significant system cost savings.

A number of external operational amplifiers and passive components, which are required today to utilize the full dynamic range of an A/D converter, can be eliminated.

This in combination with new sub-miniature packaging technology, not only reduces system cost, but at the same time can shrink the required board space by as much as 66%.

However, as more and more analog functions are integrated into microcontrollers, traditional microcontroller emulation methodologies, that were constructed for "digital" systems, become less and less suitable for the task at hand. Only if the actual microcontroller chip has the capability to act as it's own emulator, can analog signal integrity be maintained throughout the development phase all the way to production.